WAR DEPARTMENT

~~U.S. Dept. of Army~~

TECHNICAL MANUAL

GRINDING MACHINES

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TECHNICAL MANUAL No. 1-422

WAR DEPARTMENT,
WASHINGTON, *November 26, 1940.*

GRINDING MACHINES

Prepared under direction of the
Chief of the Air Corps

271023°—40——1

SECTION I

GENERAL

1. **General.**—Grinding is the process of removing material by the use of a grinding wheel mounted on a suitable machine. In the past, grinders have been known as finishing machines. Today, with the modern grinding machines and the great variety of grinding wheels available, the grinder is used for roughing as well as finishing. Most materials can be ground into cylindrical, conical, and plane surfaces accurately and economically.

a. Grinding may be divided into the following classifications and a complete description of each operation will be found in section III:

(1) Precision grinding, performed to exact limitations with strict conformity to rule or standard.

(2) Semiprecision grinding, embracing work where the limits of accuracy and finish are not as close as in precision grinding.

(3) Hand grinding, applying to operations where the work or mechanism upon which the work is mounted is held in the hands of the operator, or where the machine itself is moved by hand across the work being ground.

b. The sizes of standard grinding machines are designated by numbers which denote certain dimensions. These numbers are assigned by the manufacturer of the machine. For example, a Brown & Sharpe No. 13 universal and tool grinder will swing a grinding wheel 7 inches in diameter and has an automatic longitudinal table feed of 17 inches. The sizes of pedestal grinders are designated by the maximum diameter of the grinding wheel which may be mounted on the machine.

2. **Types.**—Grinding machines may be classified as follows:

a. Plain grinder.—This type of grinder is used for external grinding and is especially suited for grinding rolls, shafts, spindles, columns, etc. (either straight or tapered). With suitable attachments, it may be used for grinding crankshafts, cams, etc.

b. Bench precision grinder.—This type is a small, high-speed machine for external operations on small delicate work.

c. Surface grinder.—One form of grinder of this type is equipped with a straight wheel mounted on a horizontal spindle. The work is usually carried under the face of the wheel on a reciprocating table. Another form of surface grinder is equipped with a cup wheel mounted

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CHANGES No. 1

WAR DEPARTMENT,
WASHINGTON, March 14, 1942.

TM 1–422, November 26, 1940, is changed as follows:

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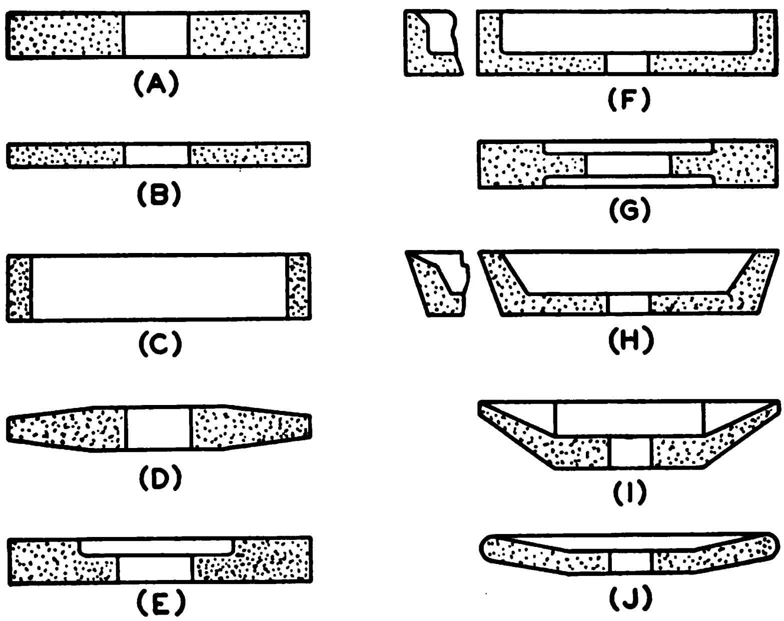

J. Saucer, saw gummer (type 13).

FIGURE 15.—Standard types of grinding wheels.

[A. G. 062.11 (1–17–24).] (C 1, Mar. 14, 1942.)

8. Selection.

* * * * * * *

b. * * *

(1) The abrasives are designated as follows:

Kind of abrasive	*Designation*
Alundum	Blank
38 Alundum	38
19 Alundum	19
15 Alundum	15

* * * * * * *

(4) The structure or "spacing of the grains" is designated by the following numbers:

446611°—42

	Close spacing	Medium spacing	Wide spacing
Structure number....	0, 1, 2, 3	4, 5, 6	7, 8, 9, 10, 11, 12

* * * * * * *

[A. G. 062.11 (1–17–24).] (C 1, Mar. 14, 1942.)

10. General.

* * * * * * *

b. When a grinding wheel * * * and will not last as long as it should. If the cutting grains **break** down faster than the bond, the face of the wheel becomes glazed and the wheel will not cut freely.

* * * * * * *

[A. G. 062.11 (1–17–24).] (C 1, Mar. 14, 1942.)

13. Grinding principles.

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f. * * *

* * * * * * *

(4) The grinding wheel face usually wears more on the edges, leaving a high spot in the center. For this reason, when starting to true a wheel, both the wheel and table should be in motion before applying the diamond point. **When rough truing, the procedure should consist of feeding the wheel into the diamond about 0.001 inch and traversing the diamond across the wheel face at a medium rate. If finer finishes are desired, after the wheel has been rough trued, the table traverse should be reduced to the slowest speed and at the same time reducing the depth of cut with the diamond.** The diamond should be fed lightly into the wheel until the sound of the diamond on the wheel indicates that it is perfectly true. The rapidity with which the diamond is moved across the wheel face depends upon the grain and grade of the wheel and the finish desired.

* * * * * * *

[A. G. 062.11 (1–17–24).] (C 1, Mar. 14, 1942.)

14. Cylindrical grinding.

* * * * * * *

b. * * *

(1) To **grind the 60° portion of the grinding machine centers—**

* * * * * * *

[A. G. 062.11 (1–17–24).] (C 1, Mar. 14, 1942.)

21. Tool and cutter grinding.

* * * * * * *

e. * * *

TABLE V.—*Cup wheel clearance angles*

[Tooth rest is set below work center as at (A), figure 37, the amount indicated below]

Diameter of cutter (inches)	Clearance angle 3° (inches)	Clearance angle 4° (inches)	Clearance angle 5° (inches)	Clearance angle 6° (inches)	Clearance angle 7° (inches)
¼	0.0066	0.0088	0.011	0.0132	0.0154
⅜	.0099	.0132	.0165	.0198	.0231
½	.0132	.0176	.022	.0264	.0308
⅝	.0165	.022	.0275	.033	.0385
¾	.0198	.0264	.033	.0396	.0462
⅞	.0231	.0308	.0385	.0462	.0539
1	.0264	.0352	.044	.0528	.0616
1¼	.033	.044	.055	.066	.077
1½	.0396	.0528	.066	.0792	.0924
1¾	.0462	.0616	.077	.0924	.1078
2	.0528	.0704	.088	.1056	.1232
2¼	.0594	.0792	.099	.1188	.1386
2½	.066	.088	.110	.132	.154
2¾	.0726	.0968	.121	.1452	.1694
3	.0792	.1056	.132	.1584	.1848
3½	.0924	.1232	.154	.1848	.2156
4	.1056	.1408	.176	.2112	.2464
4½	.1188	.1584	.198	.2376	.2772
5	.132	.176	.220	.264	.308
5½	.1452	.1936	.242	.2904	.3388
6	.1584	.2112	.264	.3168	.3696

TABLE VI.—*Straight wheel clearance angles*

Distance (B), figure 37, is obtained by raising center of wheel above center and top of tooth support, the amount indicated below]

Diameter of wheel (inches)	Clearance angle 3° (inches)	Clearance angle 4° (inches)	Clearance angle 5° (inches)	Clearance angle 6° (inches)	Clearance angle 7° (inches)
2	0. 0528	0. 0704	0. 088	0. 1056	0. 1232
2¼	. 0594	. 0792	. 099	. 1188	. 1386
2½	. 066	. 088	. 110	. 132	. 154
2¾	. 0726	. 0968	. 121	. 1452	. 1694
3	. 0792	. 1056	. 132	. 1584	. 1848
3¼	. 0858	. 1144	. 143	. 1716	. 2002
3½	. 0924	. 1232	. 154	. 1848	. 2156
3¾	. 099	. 132	. 165	. 198	. 231
4	. 1056	. 1408	. 176	. 2112	. 2464
4¼	. 1122	. 1496	. 187	. 2244	. 2618
4½	. 1188	. 1584	. 198	. 2376	. 2772
4¾	. 1254	. 1672	. 209	. 2508	. 2926
5	. 132	. 176	. 220	. 264	. 308
5¼	. 1386	. 1848	. 231	. 2772	. 3234
5½	. 1452	. 1936	. 242	. 2904	. 3388
5¾	. 1518	. 2024	. 253	. 3036	. 3542
6	. 1584	. 2112	. 264	. 3168	. 3696
6¼	. 165	. 220	. 275	. 330	. 385
6½	. 1716	. 2288	. 286	. 3432	. 4004
6¾	. 1782	. 2376	. 297	. 3564	. 4158
7	. 1848	. 2464	. 308	. 3696	. 4312

f. * * *

* * * * * * *

(3) The width of the clearance angle varies, depending on the number and depth of the flutes. **To produce a land of required width, a secondary clearance is ground on the reamer blade in a manner similar to that employed in the grinding of a milling cutter. The procedure for the grinding of the secondary clearance on a reamer may be outlined as follows:**

* * * * * * *

(6) **When grinding cutters or reamers, it is essential that all teeth be of the same height, otherwise the high teeth will do all the work. Variations in heights of teeth caused by wheel wear may be avoided by grinding completely around the cutter, then rotating the cutter 180° and grinding all the teeth again with light cuts. This** method of grinding the teeth of a reamer or cutter so that the periphery of each cutting edge is equal is shown in figures 42 and 43. The general procedure is as follows:

* * * * * * *

j. In grinding form cutters, the face of the teeth must be kept radially true and of equal height. This is accomplished by radial

grinding. A correctly ground cutter tooth is shown at (A) and **(B)**, figure 50. The tooth shown at **(C)** would drag and make a shallow cut, whereas the tooth shown at **(D)** would gouge and make an excessively deep cut. While grinding, care should be exercised to keep the tooth face square with the sides of the cutter. The right and wrong methods of grinding form cutters are shown in figure 51.

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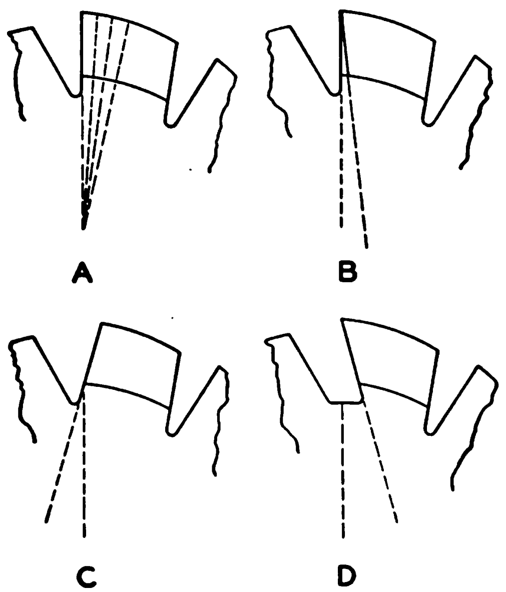
[A. G. 062.11 (1-17-24).] (C 1, Mar. 14, 1942.)



A. Correctly ground.
B. Correctly ground (with rake).
C. Incorrectly ground (ahead of center).
D. Incorrectly ground (excessive undercut).

FIGURE 50.—Correct and incorrect grinding of form cutter teeth.

[A. G. 062.11 (1-17-24).] (C 1, Mar. 14, 1942.)

24. Polishing and buffing speeds.—The proper speed for polishing and buffing is governed by the type of wheel, nature of work, and finish desired. For polishing and buffing operations in general, where the wheels are in perfect balance and correctly mounted, a speed of approximately 7,500 **f. p. m.** is safe and gives satisfactory results for most work.

[A. G. 062.11 (1-17-24).] (C 1, Mar. 14, 1942.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:
J. A. ULIO,
Major General,
The Adjutant General.

U. S. GOVERNMENT PRINTING OFFICE: 1942

on a vertical spindle. The work is carried on a reciprocating or rotating table so that its surface is brought in contact with the end of the grinding wheel.

d. Universal grinder.—This type is for general work and with the proper attachments can be adapted to most classes of grinding.

e. Internal grinder.—This type is used for finishing the inner surfaces of bushings, gears, gages, sleeves, cutters, etc.

f. Disk grinder.—This type is used extensively for facing castings as well as surfacing various other materials. It embodies two large metal disks with circular abrasive sheets secured to their faces. An adjustable work table is mounted parallel to the faces of these disks.

g. Belt grinder.—This grinder may be of the vertical or horizontal type. The grinding element consists of a belt covered with abrasive material and grinding is accomplished by holding the work against the moving belt.

h. Plain cutter grinder.—This is a machine especially suited for sharpening milling machine cutters and similar tools.

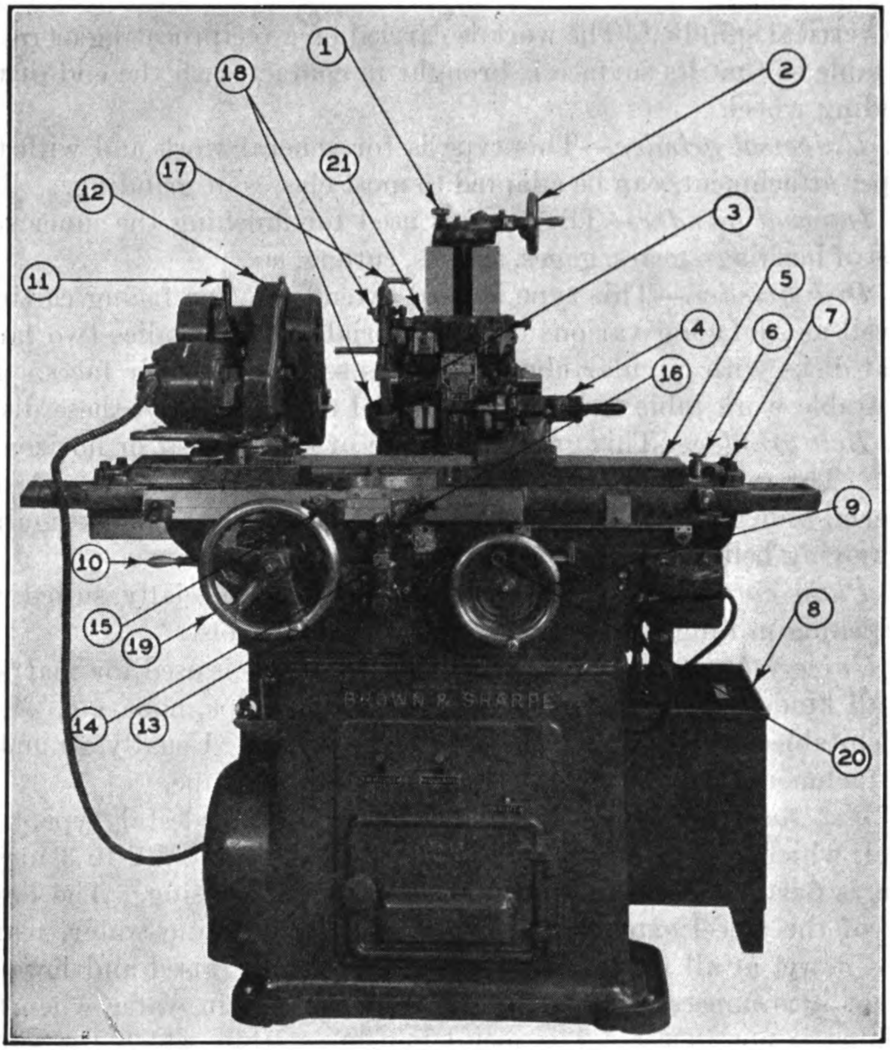
i. Universal tool grinder.—This type of machine is used for sharpening all kinds of milling cutters, reamers, saws, taps, hobs, etc. It is also suitable for cylindrical and surface grinding. Usually a number of attachments are furnished with this type of machine.

j. Wet tool grinder.—This grinder is of the pedestal type. Its wheel, which is usually 18 to 24 inches in diameter and 2 to 3 inches wide, is partially enclosed within a heavy metal housing. The lower part of the wheel extends into a receptable containing water, which keeps it wet at all times. This receptacle can be raised and lowered so that it is unnecessary for the wheel to remain in water when the machine is not in use. The metal housing within which the wheel rotates protects the operator and prevents water from being spread over the shop.

k. Pedestal grinder.—This type is used for dry grinding of cutting tools and is also used to some extent for grinding drills. The wheels swing on a horizontal shaft and are usually from 6 to 14 inches in diameter. This grinder is furnished with wheel guards and a tool rest.

l. Drill grinder.—This grinder is designed for sharpening twist drills. It is provided with an adjustable oscillating holder with a V-block to receive the drill and allow its lip to be passed across the side of the wheel with an angular, swinging motion which gives the desired cutting clearance at the point.

m. Tool post grinder.—This is a small, high-speed machine that may be mounted to the tool post on the carriage of a lathe. It is used



1. Knob for clamping elevating screw handwheel bearing after setting.
2. Handwheel for vertical adjustment of wheel slide.
3. Wheel spindle slide with self-adjusting bronze boxes.
4. Foot stock.
5. Swivel table.
6. Spring knob for engaging fine adjustment of swivel table.
7. Table clamp bolts.
8. Wet grinding attachment.
9. Handwheel for fine cross feed.
10. Lever for controlling hand and power longitudinal table travel.
11. Spindle clutch lever.
12. Headstock.
13. Table reverse lever.
14. Lever for locking hand and power longitudinal table travel.
15 and 16. Reverse dogs.
17. Coolant valve.
18. Wheel and water guards.
19. Handwheel for longitudinal table travel.
20. Thumbscrew for changing from fine to coarse feed.
21. Gage for setting wheel spindle on center.

FIGURE 1.—Universal and tool grinding machine.

extensively for grinding lathe centers as well as work set up between centers in the lathe.

n. Portable grinder.—The portable grinder may use a direct motor drive or be driven by a belt or flexible shaft. It is used for grinding castings, forgings, metal patterns, etc., where the article being ground cannot be taken to a machine that is permanently set up.

3. Attachments.—These units may be divided into two classes; standard attachments or accessories, and special attachments. The group of standard attachments that is generally furnished with the machine includes guards, dogs, wrenches, a small faceplate and chuck, back rests, center rests, and a headstock and footstock. Special attachments are any fixtures that the manufacturer may furnish in order

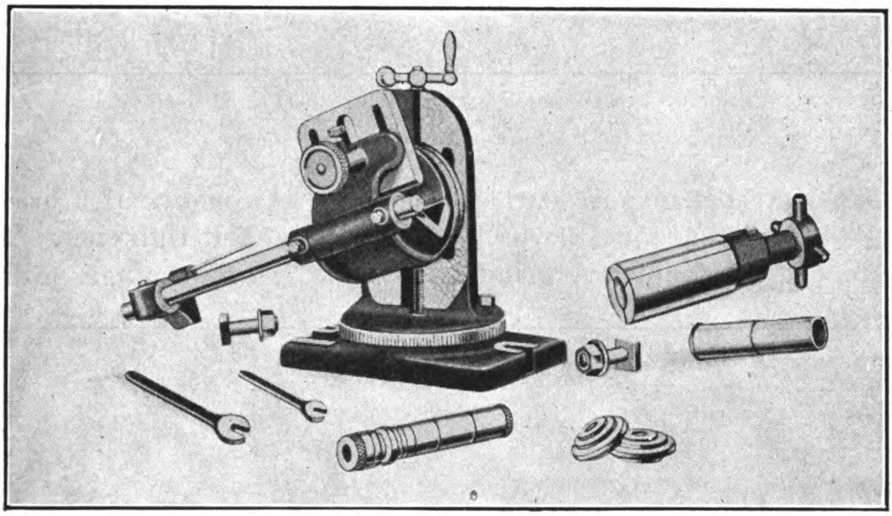


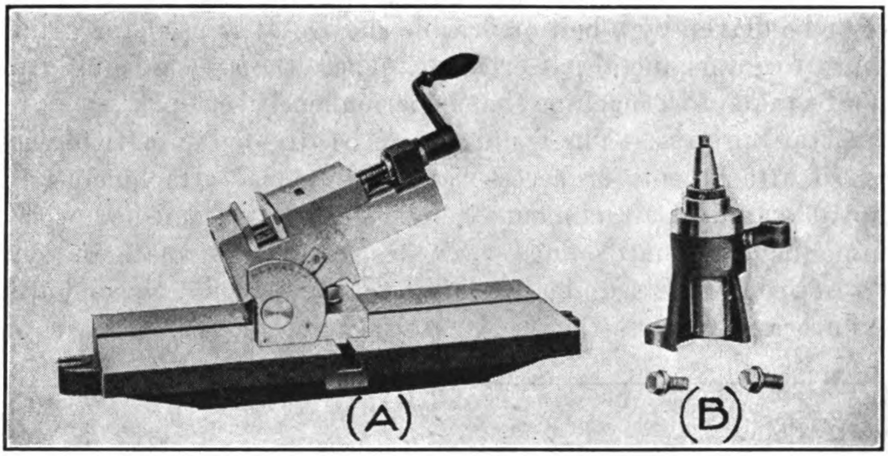
FIGURE 2.—Universal head.

to do some special class of work. The universal and tool-grinding machine (fig. 1) embodies the principles involved in most grinders and will therefore be generally used as a reference in the description of attachments given below.

a. The universal head (fig. 2) is adapted to hold various forms of milling cutters directly by their shank or on arbors. This head will also hold the cutter bar to receive work mounted on the sliding shell. The base is graduated around the entire circumference in degrees and the tool head swivels to a 90° position on either side of zero. The work head has a vertical adjustment of 4 inches to allow for the grinding of large diameter cutters.

b. The surface grinding attachment (fig. 3) is adaptable for all varieties of surface grinding. It consists of a wheel spindle extension,

an adjustable vise, and a large table plate. Some manufacturers furnish the wheel spindle extension only.



A. Adjustable vise and table plate. B. Wheel spindle extension.

FIGURE 3.—Surface grinding attachment.

c. The internal grinding attachment (fig. 4) consists of a bracket clamped to the machine, a wheel spindle, and a belt tightener. This attachment is used when grinding the inside of bushings, milling

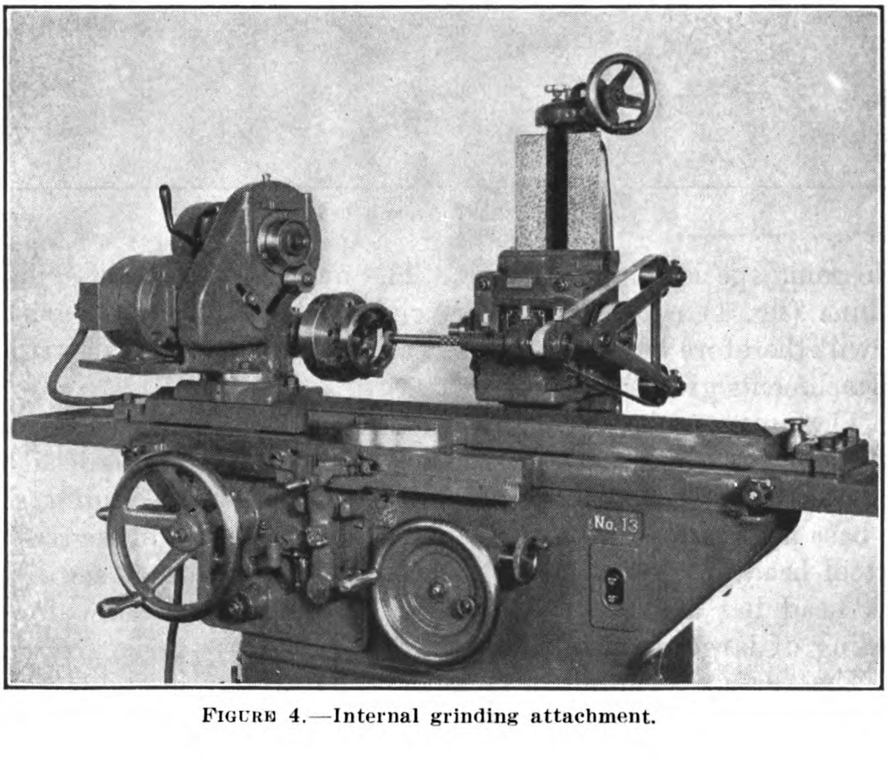


FIGURE 4.—Internal grinding attachment.

cutters, sleeves, etc., and is adaptable for either straight or tapered work. It is also used to advantage in connection with the radial grinding attachment for grinding cutters with fine teeth. The grinding spindle is small in diameter and revolves in a telescopic tube of sufficient size to give rigidity. The small diameter of the spindle enables it to run at the required high speed.

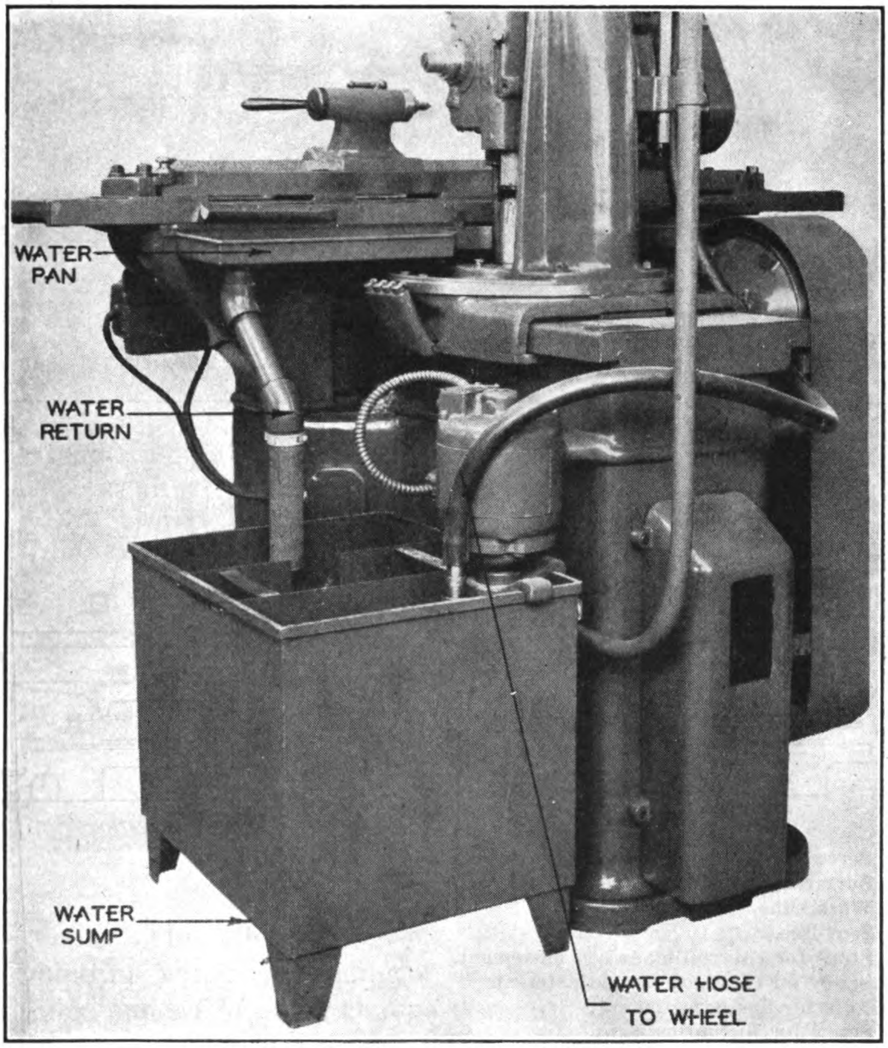


FIGURE 5.—Wet grinding attachment.

d. The wet grinding attachment (fig. 5) consists of a centrifugal pump, water sump, water pipe and trough, cast-iron wheel guards, and telescopic guards for the table. This attachment is particularly adaptable to cylindrical work but is not intended for surface, internal, or general cutter grinding.

e. The index centers (fig. 6) consist of a headstock and tailstock. An index plate is attached to the spindle of the headstock for accurate dividing, while the tailstock spindle is adjustable laterally by means

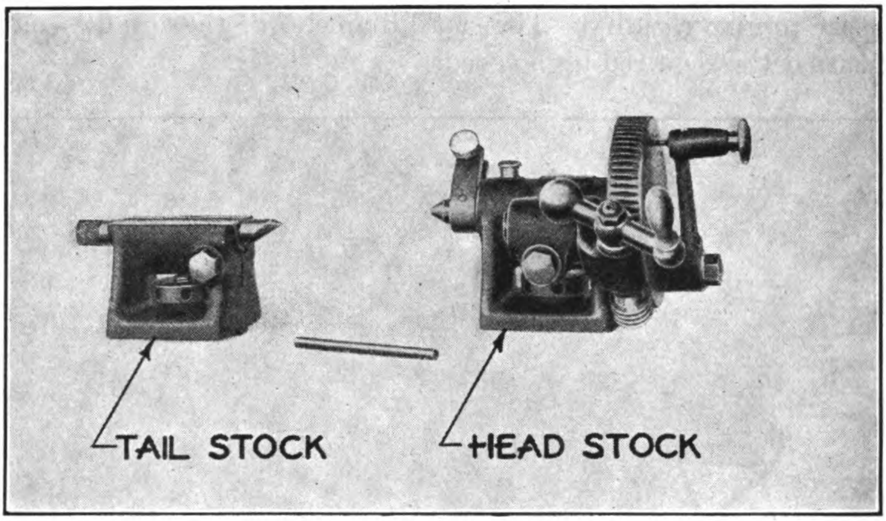
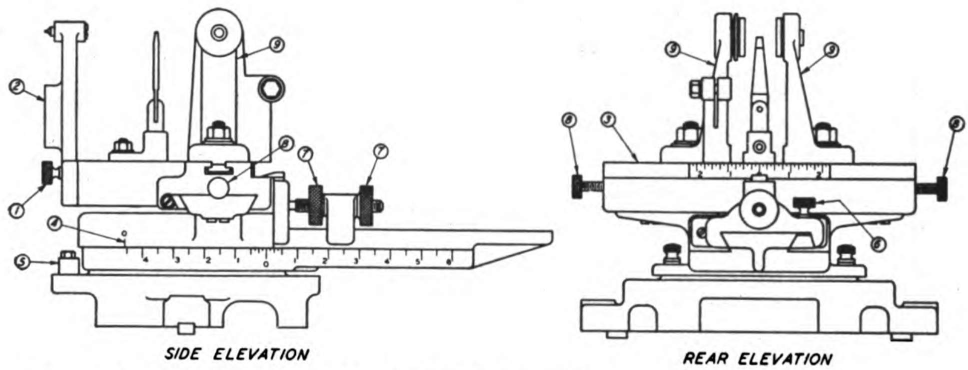


FIGURE 6.—Index centers.



1. Screw for fastening diamond point holder in position.
2. Surface for setting diamond point.
3. Work slide.
4. Zero line.
5. Stops for controlling swivel movement.
6. Screw for clamping fine adjustment.
7. Nuts for fine adjustment.
8. Screw for fine adjustment.
9. Work holders.

FIGURE 7.—Radial grinding attachment.

of a thumbscrew. The center and index plate may be revolved by a worm, or the worm may be disengaged and the plate turned by hand. It is convenient for grinding form cutters and work of a similar class and can be clamped directly to the machine table or set up on raising blocks.

f. The radial grinding attachment (fig. 7) is used for grinding convex and concave cutters as well as other work of a similar nature. In addition, it may be used to true grinding wheels to any desired radius by the use of the attached diamond point. A tooth support with the necessary adjustments is also embodied in the unit.

g. The hob grinding attachment (fig. 8) is for grinding hobs of any given lead. It consists of a headstock and tailstock similar to the ones shown in figure 6. The principal difference lies in the fact that the headstock spindle is driven from the grinder through a suitable

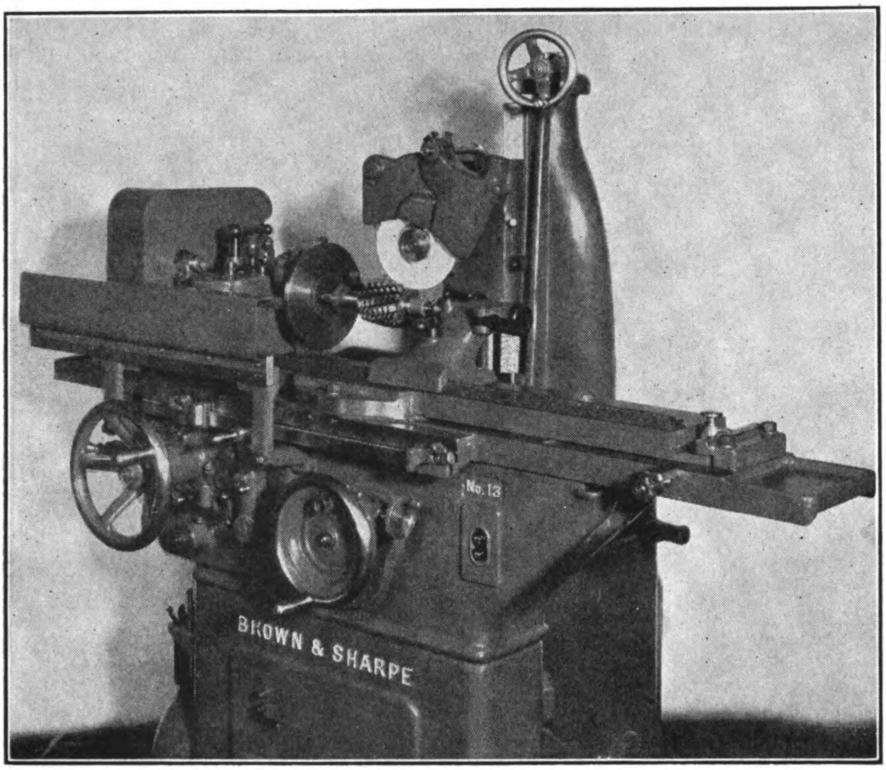


FIGURE 8.—Hob grinding attachment.

gear train. This allows the work to revolve slowly as it is fed into the grinding wheel, producing a helical cut. An index plate, gear box, rack, and set of quick-change gears are included with the attachment.

h. The angular wheel truing attachment (fig. 9) is similar in design to the compound rest on a lathe and provides an accurate means of producing angular shapes on abrasive wheels. The longitudinal slide is manually operated by a hand crank and the swivel base of the attachment is graduated in degrees. The diamond tool holder, mounted on the slide, can be set to produce any desired angle.

i. The radius truing attachment (fig. 10) consists of a diamond point mounted in a swivel holder which is clamped to the table of the grinder. By adjusting the position of the diamond point, the grinding wheel may be trued to any desired radius.

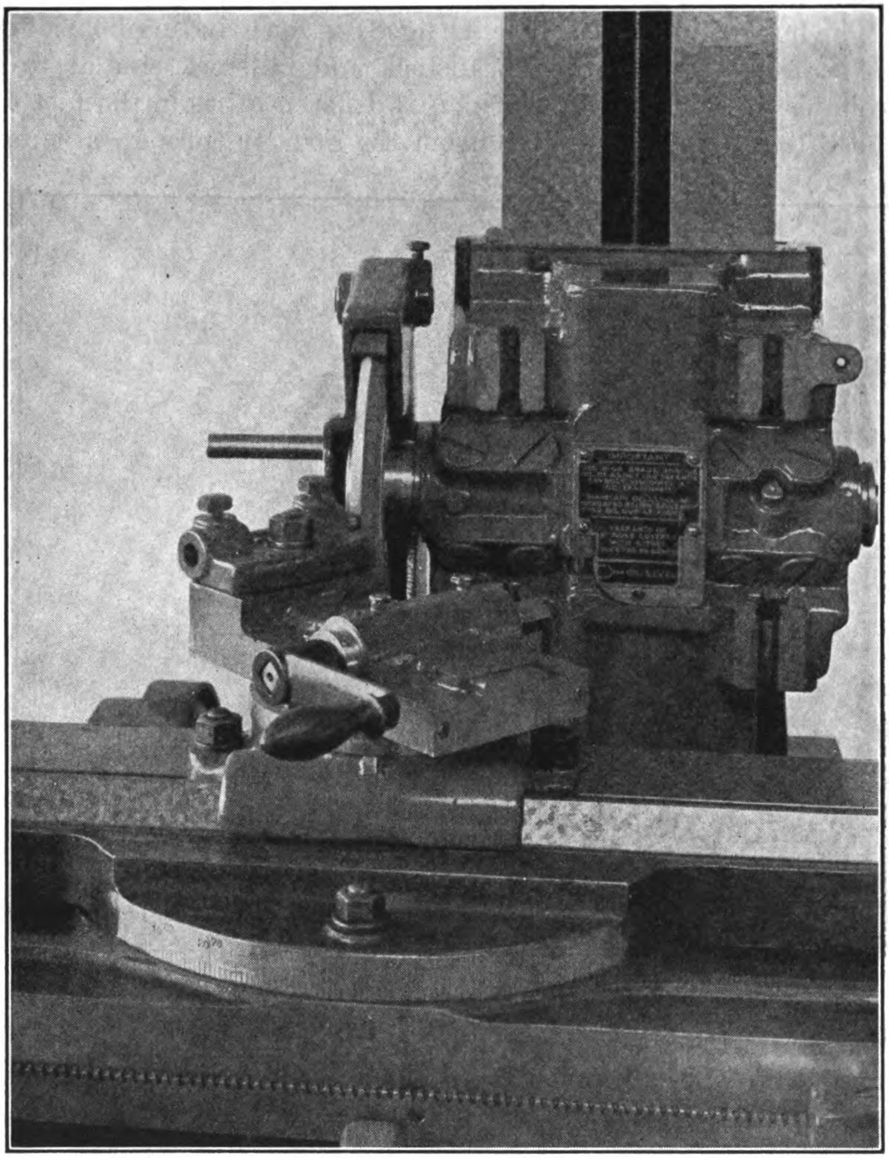


FIGURE 9.—Angular wheel truing attachment.

j. The taper holding attachment (fig. 11) is used in connection with the universal head. It will hold various types of cutters up to 8 inches in diameter and can be raised or lowered to any desired position. The swivel base is graduated around its entire circumference in degrees.

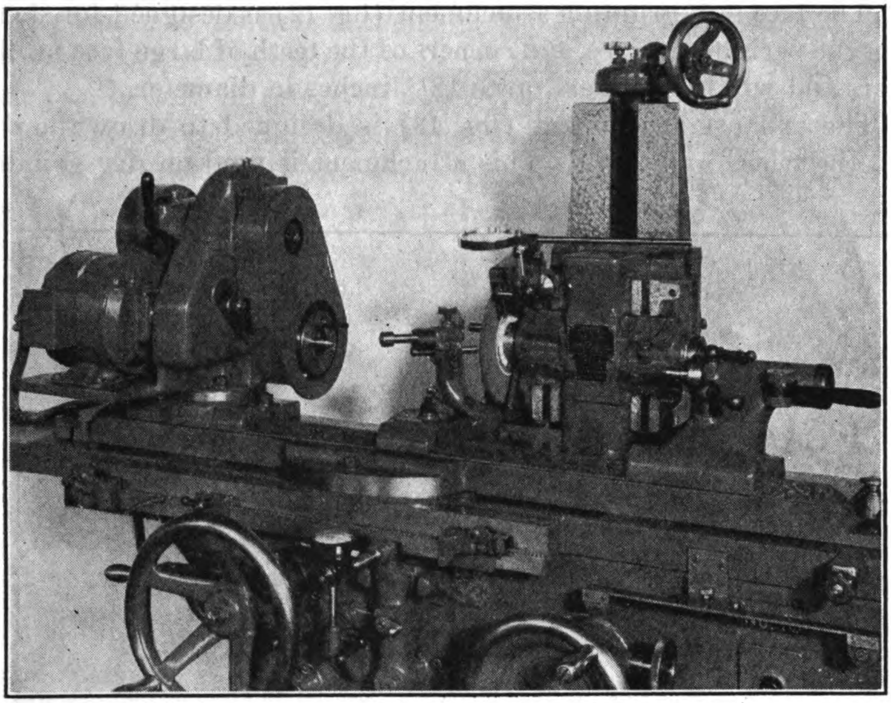


FIGURE 10.—Radius truing attachment.

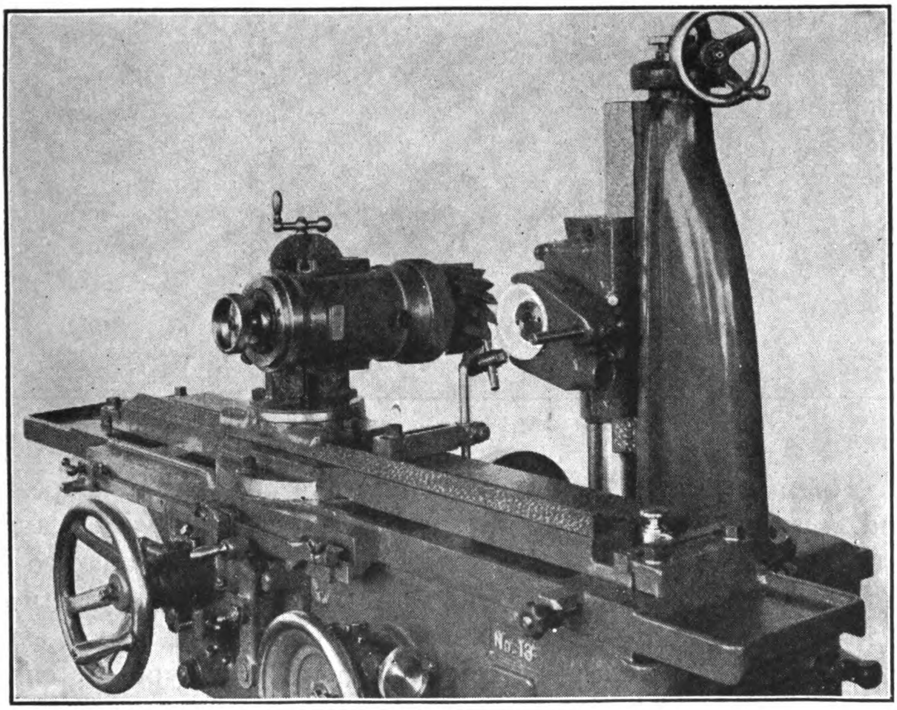


FIGURE 11.—Taper holding attachment.

k. The face mill grinding attachment (fig. 12) is designed for sharpening the periphery, sides, and corners of the teeth of large face milling cutters and will take cutters up to 18½ inches in diameter.

l. The exhaust attachment (fig. 13) is designed to draw the dust from the wheel and work. This attachment is used on dry grinding only.

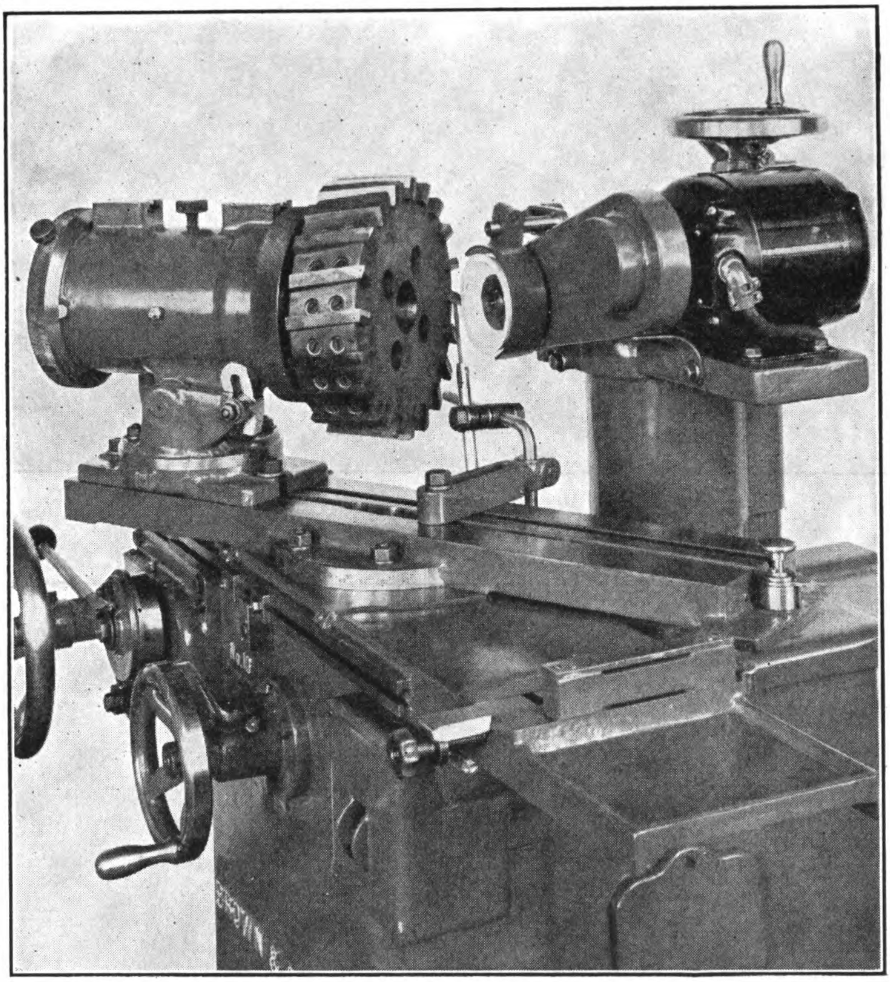


FIGURE 12.—Face mill grinding attachment.

m. The magnetic chuck may be round or rectangular in shape. If round, it is mounted on the headstock spindle revolving with it and if rectangular, is clamped to the table. It is especially adapted for grinding piston rings and other thin work that could not be practically held in a jaw-type chuck. The rectangular chuck is used most extensively in connection with surface grinding. Both types of chucks may operate on either 115 or 230 volts direct current. Permanent magnetic chucks are available in addition to the electro-magnetic

types and are self-contained, having powerful holding ability. There is no installation, running, or maintenance cost involved and they can be left in the "on" position indefinitely without injury to the chuck. The permanent magnetic chuck may be used on any machine or independently as a surface plate. Magnetized master blocks are often used in connection with the magnetic chuck. They are steel

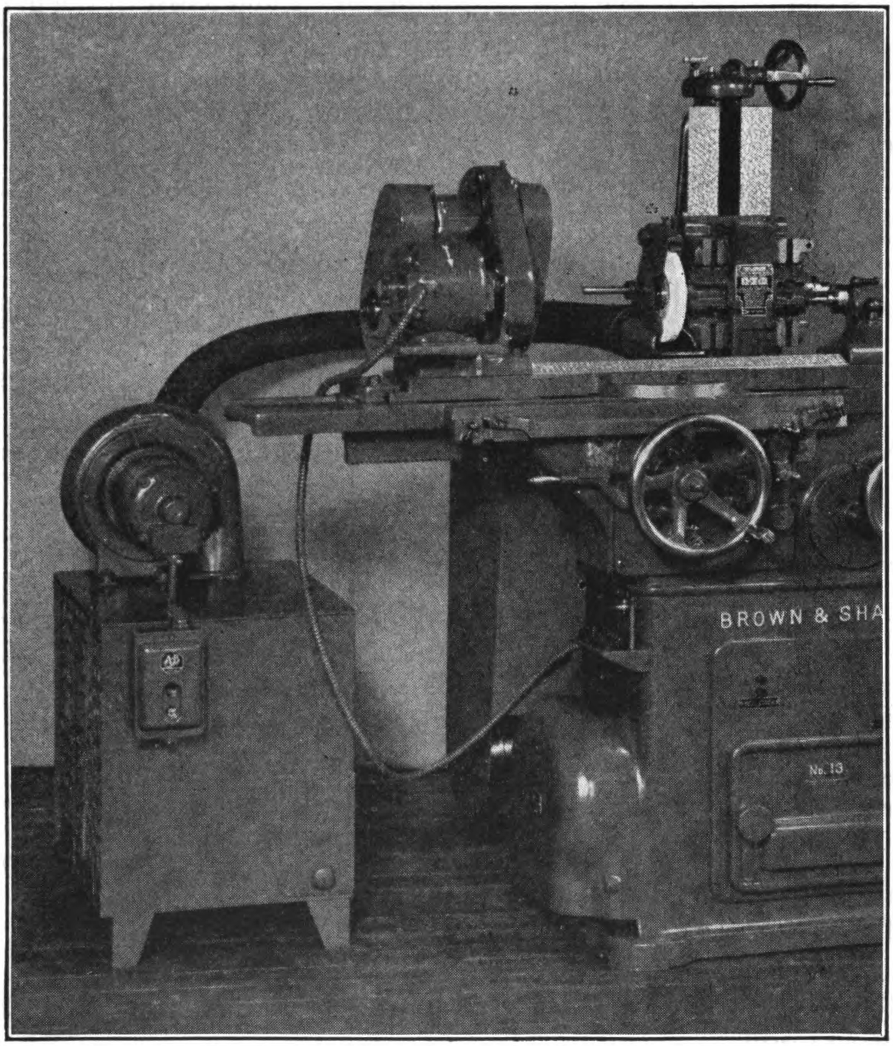


FIGURE 13.—Exhaust attachment.

blocks, hardened, ground, and lapped to size, and may be of any desired size and shape. Work being ground is held between two or more of these blocks, allowing the magnetic circuit to pass through it, and holding the entire set-up firmly to the chuck.

4. Care.—Because of the high speed at which the grinding wheels run, it is essential that the spindle bearings are kept clean, properly

adjusted, and well-oiled. Do not allow abrasive material and dirt from the wheel and work to gather on the moving parts of the machine. Keep all finished surfaces clean and oiled. When using water, be sure that all finished surfaces are dry before leaving the machine for any length of time. Keep all nuts and bolts tight. Be sure that all work is properly set up before starting to grind. The following precautions should help keep the machine in running order and assist in the grinding operations:

a. Do not allow dirt or grit to enter oil holes.

b. Do not operate a grinding machine at a speed that will cause vibration.

c. Do not start to grind until the speed of the grinding wheel is correct.

d. Do not use a belt of uneven thickness to drive the wheel.

e. Do not leave the machine for any length of time without cleaning and drying it thoroughly.

f. Do not forget that soda added to the water helps to keep work and machine from rusting.

g. Do not forget to clean the table thoroughly before placing any of the attachments or work on it.

Section II

GRINDING WHEELS

5. General.—*a.* The following physical characteristics are common to all types of abrasive wheels:

(1) Abrasive or cutting grain.

(2) Bond substance that holds the grains in place.

(3) Voids or air spaces that provide clearance for chips cut by the abrasive grain.

b. There are many materials used in the manufacture of grinding wheels. Those such as emery and corundum are classed as natural abrasives, while carborundum, carbolite, carbora, alundum, and crystolon denote an artificial or laboratory product. For certain classes of grinding, the artificial material is found to be superior to the natural abrasives and for this reason is used in a greater percentage of grinding wheels.

c. The artificial abrasives used in grinding wheels may be divided into two general groups: aluminous and silicon carbide. Both are products of the electric furnace but differ in characteristics. Aluminous abrasive grains, while not as hard as those of silicon carbide, are tougher and do not fracture as easily. They are also able to withstand a greater stress than the silicon carbide grains which are very hard and brittle.

d. Because of the difference in physical characteristics, aluminous abrasive wheels are generally used for grinding materials of relatively high tensile strength while silicon carbide is adaptable for use with the more common grades of material.

e. The term "grain" is commonly used when referring to the abrasive or cutting particles of the wheel. The abrasives used for grinding wheels are crushed and sized through carefully made screens. The number used to designate grain size refers to the mesh per linear inch in the screens through which the crushed abrasive passes. For example, a No. 36 grain is that which passes through a screen having 36 wires per linear inch or 1,296 meshes or apertures per square inch.

f. "Grade" designates the degree of hardness of a grinding wheel. For example, a soft wheel is one on which the cutting particles wear or break away rapidly, while a hard wheel is one that effectively opposes this action. Most manufacturers use a system whereby the grade is designated by letters ranging from E (very soft) to Z (very hard).

g. "Bonding" is the process of binding or holding the abrasive material together. Five methods of bonding described below are in common use and each is especially adapted to certain grinding requirements.

(1) The majority of grinding wheels are made by the vitrified process and may be either puddled or pressed. In this process, the abrasives are carefully sized and weighed, then either puddled in molds or pressed. If pressed, the pressure may run as high as 4,000,000 pounds and varies with the structure of the wheel. After molding or pressing, the wheels are dried and carefully set in ovens or kilns where they are burned. Great care is required in setting to prevent warping or cracking of the wheels during this process. The kilns are fired to a temperature high enough to flow and vitrify the material. The time required for burning depends upon the size of the wheels and varies from 2½ days to 2 weeks. After the burning process, the wheels go to the truing room where they are mounted in lathes and trued to dimension with a hardened conical cutter.

On leaving the truing room, the wheels are bushed, balanced, tested for speed, and inspected for errors in shape, size, grain, and grade. Cracks, chipped edges, and blowholes are also causes for rejection. The testing speed used is approximately 50 percent greater than the recommended operating speed. The vitrified wheel has several qualities which make it preferable for over 75 percent of the grinding operations. It has porosity as well as strength of bond, and the material removed per cubic inch of wheel wear is high. It is not affected by water, acids, oils, or ordinary temperatures and is uniform in hardness.

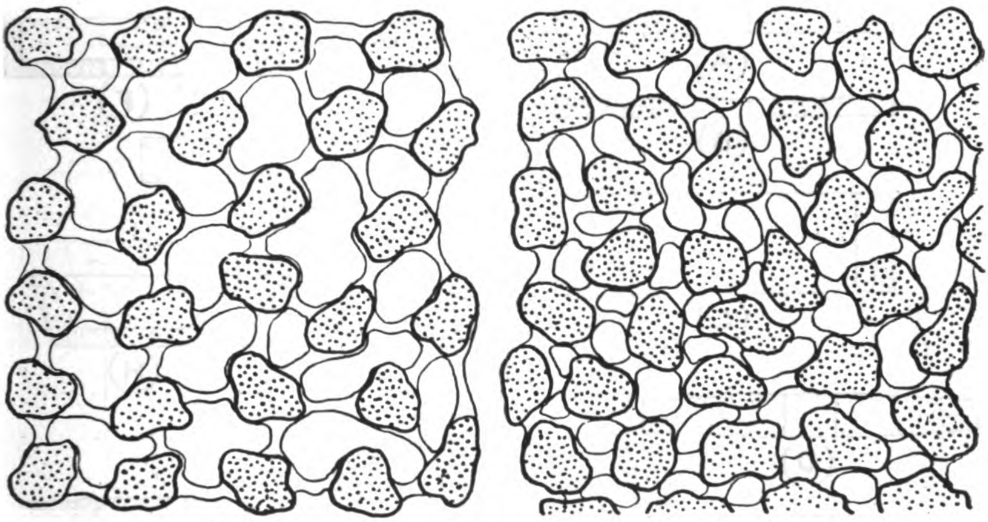
(2) The bonding agent of silicate wheels is principally silicate of soda. This bond permits the release of abrasive grains more readily than in the vitrified wheels and the resultant cutting action is milder. They are used primarily for grinding edged tools and are important where heat generated in grinding must be kept at a minimum. Many of the large solid wheels are manufactured by this process.

(3) Resinoid bond is a phenolic resin compound. Resinoid wheels are porous in structure, cool cutting, and remove stock rapidly. They are generally used for snagging castings, cutting-off, grinding rolls, and gumming saws.

(4) The bond in rubber wheels is pure rubber plus sulphur as a vulcanizing agent. These wheels are chiefly used where a fine finish is required. The rubber softens under the heat of grinding and acts as a cushion for the abrasive so that it does not cut as deeply as a wheel more rigidly bonded. The rubber also acts as a buffer to polish out the grain marks. Extremely thin wheels can be made with this bond because of its strength and toughness. For example, wheels as thin as 0.005 inch are used for slotting pen points. These wheels operate economically at either high or low speeds.

(5) In shellac bonded wheels the abrasive material is mixed with the shellac in a steam-heated mixing machine which thoroughly coats the abrasive particles with the bond. Wheels 1/8 inch thick or less are made to exact size in heated steel molds while thicker wheels are pressed hydraulically in similar molds. After forming, the wheels are placed in sand and baked for a few hours at approimately 300° F. These wheels are classed as elastic or organic and have a cool cutting action making them adaptable for finishing work. Since shellac is somewhat elastic and softens under the heat of grinding, its action is similar to rubber but cuts more freely and will take deeper cuts without burning.

h. The structure of a grinding wheel is classed as to the density of the grain or the number of grains per cubic inch of wheel volume. Figure 14 shows the structure of two wheels of identical grain size and bond but which differ greatly in cutting action because of the difference in the spacing of the grains. Combination wheels are made by mixing several sizes of abrasive together. Three numbers are generally used, such as 24, 36, and 46. The coarse abrasive is for fast cutting while the finer grain produces a smooth finish. These wheels are generally bonded by the vitrified process. They are strong and durable and are used to some extent for cylindrical grinding of steel.



① Wide spacing. ② Close spacing.

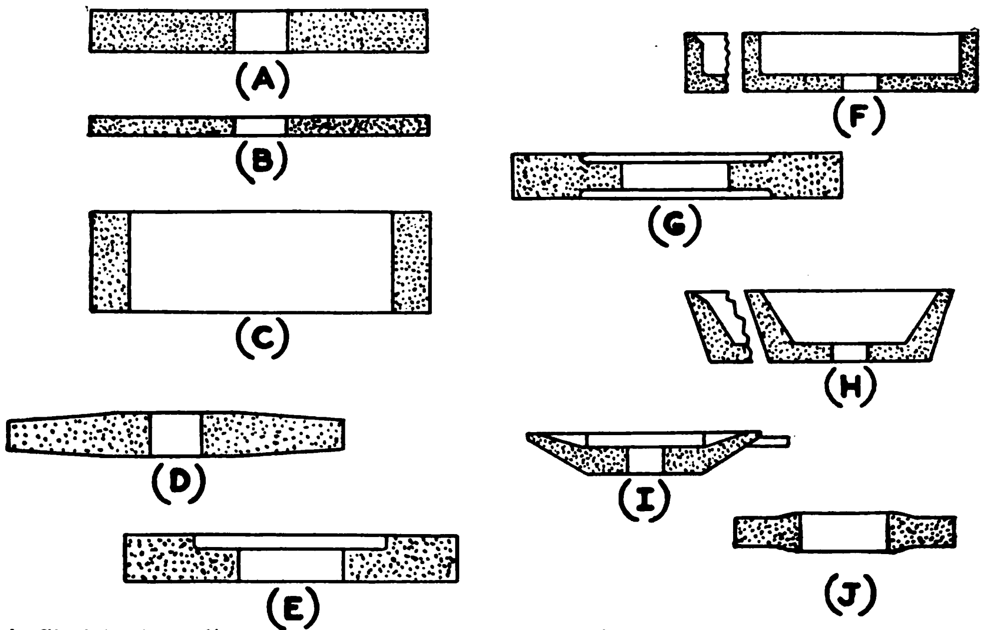
FIGURE 14.—Grinding wheel abrasive spacing.

6. Care.—*a.* When grinding wheels are received, they should be closely inspected to make sure that they have not been injured in packing and shipping. This inspection may be made by observing the wheel closely for broken edges. As an added precaution, each wheel should be tapped gently while suspended on a small piece of solid metal. If the wheel has a clear ring it is usually free from cracks but should the tapping indicate a crack, the wheel should not be used. When applying the test the wheels should be dry and free from sawdust.

b. Extreme care should be taken in the storage of wheels. Suitable racks and bins should be provided to accommodate the various types and shapes allowing the larger straight and tapered wheels to be supported on their edges. Thin rubber, shellac, and other organically bonded wheels should be laid flat on a plane surface to prevent warpage. Cup and similarly shaped wheels should be stacked on the flat

sides with corrugated paper or other cushioning material between them. Small wheels may be stored in boxes, bins, or drawers while very large wheels are usually left in their original containers. Wheels should be stored in a dry room with each bin or drawer numbered and tagged with the type, size, and kind of wheel it contains. This makes it unnecessary to remove the wheel when such information is required.

c. Wheels should be very carefully handled to prevent damage due to dropping, etc. In handling wheels, care should be exercised so as to not destroy the small tag that is glued to them. This tag has the following information: Type of wheel, manufacturer's number, cus-



A. Straight (type 1).
B. Cut-off wheel (type 1).
C. Cylinder or ring (type 2).
D. Tapered (type 4).
E. Recessed, one side (type 5).
F. Straight cup (type 6).
G. Recessed, two sides (type 7).
H. Flaring cup (type 11).
I. Dish (type 12).
J. Raised dovetail (type 10).

FIGURE 15.—Standard types of grinding wheels.

tomer's number, size, grain, grade, structure, testing speed (r. p. m.), and recommended speed (r. p. m.). This information is useful when a duplicate wheel is to be requisitioned or when the wheel speed is required.

7. Shapes.—*a.* Standard shapes of grinding wheels are shown in figure 15.

b. Grinding wheels also have standard shaped faces. These shapes are designated by letters as shown in figure 16.

8. Selection.—*a.* Conditions under which wheels are used vary considerably and a wheel that is satisfactory on one machine may be

too hard or too soft for the same operation on another. The following basic factors must be considered when selecting grinding wheels although it should be understood that the rules and conditions listed are flexible and subject to occasional exceptions.

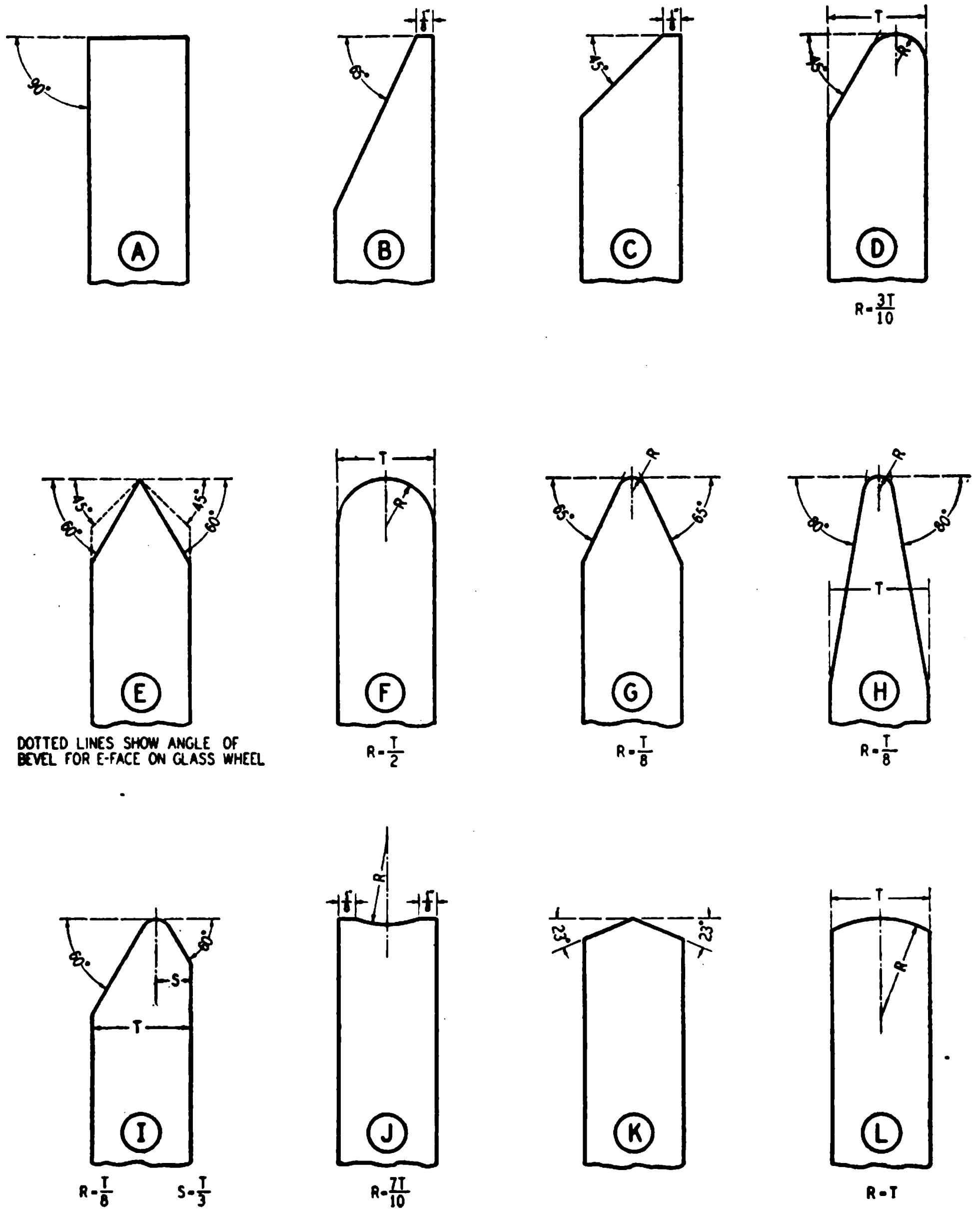


FIGURE 16.—Standard types of grinding wheel faces.

(1) The main factor in the selection of the abrasive to be used is the tensile strength of the material to be ground.

(*a*) An aluminous abrasive should be used for materials of high tensile strength such as carbon steel, high-speed steel, stellite, malleable iron, hard bronze, etc.

(*b*) A silicon carbide abrasive should be used for materials of low tensile strength such as grey iron, chilled iron, brass and soft bronze, cemented carbides, etc.

(2) Factors affecting the grain size are:

(*a*) The softer and more ductile the material, the coarser the grain size.

(*b*) The larger the amount of stock to be removed, the coarser the grain size.

(*c*) The better the finish required, the finer the grain size.

(3) Factors affecting the grade are:

(*a*) The harder the material, the softer the grade should be.

(*b*) The smaller the area or arc of contact, the harder the grade should be. By "arc of contact" is meant the length of the arc (measured along the periphery of the wheel) that is in contact with the work being ground.

(*c*) The higher the work speed with relation to wheel speed, the milder the resulting grinding action and the harder the grade should be.

(*d*) The greater the vibration in the grinding machine, the harder the wheel should be.

(*e*) A harder grade wheel can usually be used when a satisfactory coolant is used.

(4) Factors affecting the structure are:

(*a*) The softer, tougher, and more ductile the material, the wider the grain spacing should be.

(*b*) The finer the finish desired, the denser the structure or the closer the grain spacing should be.

(*c*) Surfacing operations require open structures or wide grain spacing.

(*d*) Cylindrical, centerless operations, including tool and cutter grinding, are usually best performed with wheels of medium structure or grain spacing.

(5) Factors affecting the bond are:

(*a*) Thin cut-off wheels and others subjected to bending strains require resinoid, shellac, or rubber bonds.

(*b*) Solid wheels of very large diameters require a silicate bond.

(*c*) Vitrified wheels are usually best for speeds up to 6,500 s. f. p. m. (surface feet per minute) and resinoid, shellac, or rubber wheels for speeds above 6,500 s. f. p. m.

(*d*) Resinoid, shellac, or rubber bonds are generally best where a high finish is required.

b. Norton grinding wheels are used extensively for all classes of grinding, therefore the identifying characteristics of these wheels will be used as a reference.

(1) The abrasives are designated as follows:

Kind of abrasive	*Designation*
Alundum	Blank
38 Alundum	38
19 Alundum	29
15 Alundun	15
35 Alundum	35
37 Crystolon	37
34 Crystolon (green)	34

(*a*) From the above table it is noted that the Norton Company manufactures five types of alundum abrasives and two types of crystolon abrasives. These different abrasives possess individual characteristics, principally with respect to "temper" or "frayability," which make them adaptable to the various classes of work.

(*b*) Wheels are also manufactured in different colors. The Norton "BE" bond wheel is white and is used extensively for toolroom grinding. The "34" crystolon wheel is green in color and is made from a special grade of silicon carbide that is hard and sharp, while the bond gives it an open porous structure. These characteristics are necessary to provide good cutting qualities and make it especially adapted to the grinding of cemented carbide tools and cutters.

(2) The grain size is expressed by the following numerals:

Very coarse	Coarse	Medium	Fine	Very fine	Flour sizes
8	12	30	70	150	280
10	14	36	80	180	320
	16	46	90	220	400
	20	60	100	240	500
	24		120		600

(3) The grade is expressed by the following letters:

Very soft	Soft	Medium	Hard	Very hard
E, F, G	H, I, J, K	L, M, N, O	P, Q, R, S	T, U, W, Z

(4) The structure or "spacing of the grains" is designated by the following numbers:

	Close spacing	Medium spacing	Wide spacing
Structure number	1, 2, 3	4, 5, 6	7, 8, 9, 10, 11, 12

NOTE.—Some types of wheels are produced in only one structure in which case no structure number is given.

(5) The bond is designated by the following letters:

Vitrified	No. letter
BE vitrified	BE
Silicate	S
Shellac	L
"V" shellac	V
Resinoid	T
Rubber	R

c. The following grinding wheel numbers illustrate the scheme of identification.

(1) No. 3846—M5BE:

38 Alundum abrasive.
46 Grain size.
M Grade.
5 Structure.
BE Vitrified bond.

(2) No. 60—N8T:

— Alundum abrasive.
60 Grain.
N Grade.
8 Structure.
T Resinoid bond.

(3) No. 3770—J5L:

37 Crystolon abrasive.
70 Grain.
J Grade.
5 Structure.
L Shellac bond.

(4) No. 34100—H7:

34 (green) Crystolon abrasive.
100 Grain.
H Grade.
7 Structure.
— Vitrified.

(5) Combination wheels are designated by the letter "C" after the grain size, thus 24CM.

d. Norton grinding wheels recommended for various operations are listed in table I.

TABLE I.—*Application of Norton grinding wheels*

Class of work	Operation	Grinding wheel No.
Aluminum	Cylindrical grinding	3730—J8.
Do	Surface grinding	3846—H8BE.
Do	Snagging	3724—06.
Armatures (laminations).	Cylindrical grinding	36—L5BE.
Brass and soft bronze	Cylindrical grinding	3736—K5.
Do	Internal grinding	3736—J6.
Do	Surface grinding (straight wheel)	3736—J6.
Do	Snagging	3724—Q6.
Bronze (hard)	Cylindrical grinding	46—K5BE.
Do	Internal grinding	3860—J5BE.
Do	Snagging	20—Q8BE.
Bushings (hardened steel).	Cylindrical grinding	60—L5BE.
Do	Internal grinding	3860—K5BE.
Cast Iron	Cylindrical grinding	3736—J5.
Do	Internal grinding	3746—J5.
Do	Surface grinding (straight wheel)	3730—J8.
Do	Snagging	3716—S5.
Centers (lathe, hardened).	Cylindrical grinding	3846—L5BE.
Chisels	Sharpening	46—M5BE.
Commutators	Finishing	3760—M4L.
Copper	Cylindrical grinding	3770—J5L.
Cutters	Milling (backing off)	3846—K5BE.

TABLE I.—*Application of Norton grinding wheels*—Continued

Class of work	Operation	Grinding wheel No.
Drills	Small, off-hand sharpening	60—N5BE.
Do	Large, off-hand sharpening	46—P5BE.
Gages (hardened)	Cylindrical grinding	3880—K5BE.
Do	Surface grinding (straight wheel)	3880—I8BE.
Machine-shop grinding	General off-hand	30—P5BE.
Monel metal	Snagging	24—Q5BE.
Needles	Pointing	70—Q.
Piston (aluminum)	Cylindrical grinding	3736—J5.
Piston (cast iron)	Cylindrical grinding	3736—K5.
Reamers	Cylindrical grinding	3846—M5BE.
Do	Backing-off	3846—L5BE.
Do	Fluting	3846—L5BE.
Rubber (hard)	Cylindrical grinding	3730—K5T2.
Rubber (soft)	do	3724—K5L.
Saws (circular)	Gumming	1946—M.
Saws (metal slitting)	Backing-off	60—P.
Scissors and shears	Resharpening	120—L.
Steel (hard)	Cylindrical grinding	3846—L5BE.
Do	Surface grinding (straight wheel)	3836—H8BE.
Do	International grinding	3860—J5BE.
Do	Cutting-off	46—Q8T-2.
Steel (soft)	Cylindrical grinding	46—N5BE.
Do	Surface grinding (straight wheel)	3836—L8BE.
Do	Internal grinding	3846—L5BE.
Steel (stainless)	Cylindrical	3746—M5.

TABLE I.—*Application of Norton grinding wheels*—Continued

Class of Work	Operation	Grinding wheel No.
Stellite	Off-hand tool grinding	46—M5BE.
Taps	Fluting	60—RR.
Tools (lathes and planer)	Off-hand sharpening	60—N5BE.
Tungsten-carbide alloy	Off-hand grinding	3460—17.
Do	(Roughing)	100—C25.
Do	(Finishing)	120—C25.
Tungsten-carbide	Surface	37100—G9.
Valve	Grinding seats	80—OLBE.
Valves, tappets, and stems.	Cylindrical grinding	46—M5BE.
Vascoloy	Off-hand tool grinding	3760—17.
Do	(Roughing)	3760—17.
Do	(Finishing)	37100—H7.
Widia metal	Off-hand grinding	
	(Roughing)	3760—17.
	(Finishing)	37100—H9.
Welds	Smoothing	
	Slow speed	24—Q8BE.
	High speed	24—R4T-2.

9. Mounting.—*a.* One of the most important considerations in connection with the use of grinding wheels is that they shall be properly mounted upon the correct size spindle and between properly designed flanges and wheel guards. The correct size of arbor hole for wheels of varying diameters and thicknesses is given in table II.

Table II.—*Size of arbor hole for grinding wheels*

Diameter of wheel (inches)	Thickness of wheel (inches)													
	1/4	3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3
	Size of arbor holes (inches)													
6	1/2	1/2	1/2	1/2	1/2	1/2	5/8	5/8	3/4	3/4	3/4	3/4	3/4	3/4
7	1/2	1/2	1/2	1/2	5/8	5/8	5/8	3/4	3/4	3/4	3/4	3/4	3/4	1
8	5/8	5/8	5/8	5/8	5/8	5/8	3/4	3/4	3/4	1	1	1	1	1
9	5/8	5/8	5/8	5/8	3/4	3/4	3/4	3/4	1	1	1	1	1	1 1/4
10	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4	1	1	1	1 1/4	1 1/4	1 1/4
12	3/4	3/4	3/4	3/4	3/4	1	1	1	1	1	1	1 1/4	1 1/4	1 1/4
14	7/8	7/8	7/8	7/8	1	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2

b. If the wheel to be used has a larger hole than the spindle of the machine, a suitable bushing should be installed. If the bushing is too small, it may be scraped until it is a slip fit on the spindle. The size and design of flanges for the various sizes of grinding wheels are given in figure 17, while the right and wrong methods of mounting a grinding wheel are shown in figure 18.

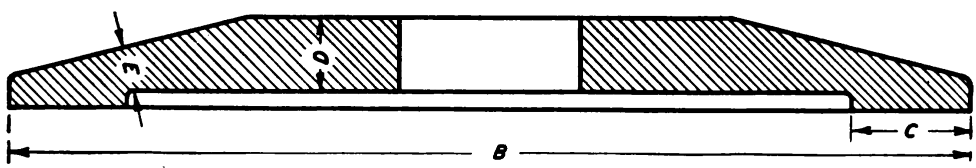


Figure 17.—Dimensions of straight flanges.

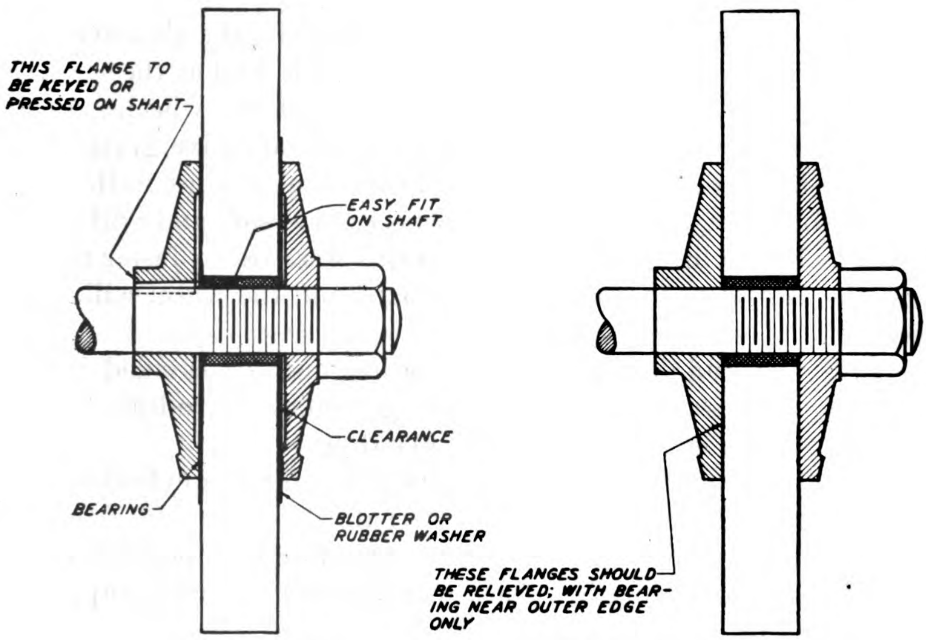
c. Compressed washers of heavy paper, pulp, or blotter material slightly larger than the flange should be used between the flanges and the wheel to serve as a cushion.

d. The spindle should revolve in a direction which will tend to tighten the spindle nut as the machine is being operated. To remove the nut, it should be turned in the direction the spindle revolves when in operation. To tighten, the spindle nut should be drawn up enough to hold the wheel securely between the flanges but not so tight that an undue strain will be put on the wheel.

e. Protective hoods or guards should always be used while grinding. Where a coolant is used, the hoods are designed to take the coolant away from the wheel. A guard of this type can be seen in figure 1

(18). When installing guards, care should be taken to prevent the guard from touching the wheel.

A	B	C		D	E
Diameter of wheel (inches)	Minimum outside diameter of flanges (inches)	Radial width of bearing surface (inches)		Minimum thickness of flange at bore (inches)	Minimum thickness of flange at edge of recess (inches)
		Minimum	Maximum		
1	3/8	1/16	1/8	1/16	1/16
2	3/4	1/8	3/16	1/8	3/32
3	1	1/8	1/4	3/16	3/32
4	1 1/4	3/16	3/8	3/16	1/8
5	1 1/2	3/16	3/8	1/4	1/8
6	2	1/4	1/2	3/8	3/16
8	3	1/4	1/2	3/8	3/16
10	3 1/2	5/16	5/8	3/8	1/4
12	4	5/16	5/8	1/2	5/16
14	4 1/2	3/8	3/4	1/2	5/16
16	5 1/2	1/2	1	1/2	5/16
18	6	1/2	1	5/8	3/8
20	7	5/8	1 1/4	5/8	3/8
22	7 1/2	5/8	1 1/4	5/8	7/16
24	8	3/4	1 1/4	5/8	7/16
26	8 1/2	3/4	1 1/4	5/8	1/2
28	10	7/8	1 1/2	3/4	1/2
30	10	7/8	1 1/2	3/4	5/8
36	12	1	2	7/8	3/4



① Right method. ② Wrong method.

FIGURE 18.—Correct and incorrect methods of mounting a grinding wheel.

SECTION III

GRINDING OPERATIONS

10. General.—*a.* Efficient grinding depends primarily upon the proper set-up of the machine being used. If the machine is not securely mounted, vibration will result, causing the grinder to produce an irregular surface. Improper alinement also affects the grinding accuracy and it is good practice to check the security and plumb of the machine every few months. It is advisable to place a strip of cushioning material under the mounting flanges, along with any necessary alining shims, to help absorb vibration.

b. When a grinding wheel is working properly, the abrasive grains cut very small chips from the work being ground and at the same time the work wears away a portion of the bond of the wheel. As long as the bond is being worn away as fast as the abrasive grains of the wheel are being dulled, the wheel will continue to work well. If the bond is worn away too rapidly, the wheel is too soft and will not last as long as it should. If the cutting grains wear down faster than the bond, the face of the wheel becomes glazed and the wheel will not cut freely.

c. Precision and semiprecision grinding may be divided into the following classes: cylindrical grinding, conical grinding, internal grinding, surface grinding, and tool grinding.

(1) Cylindrical grinding denotes the grinding of a cylindrical surface and may be either internal or external.

(2) Conical grinding pertains to the grinding of tapered work.

(3) Internal grinding is a form of cylindrical grinding applied to the finishing of bores, etc.

(4) Surface grinding is the grinding of a simple plane surface.

(5) Tool and cutter grinding pertains to the grinding of tool and cutter bits, gages, milling cutters, reamers, etc.

d. After the correct wheel has been selected and mounted and the work properly set up, the following rules with respect to the manipulation of the wheel and work should be observed:

(1) See that grinding machine is level and rigidly secured to the floor.

(2) Be sure grinding wheel is perfectly sound and in good balance. (Wheels which are out of balance may be responsible for chatter marks in the finished surface.)

(3) As far as possible, maintain a wheel speed of between 5,000 and 6,500 f. p. m.

(4) On long work, use a sufficient number of center rests, properly applied, to prevent chattering.

(5) Eliminate all sources of vibration in the grinding machine, particularly where a fine finish is important.

(6) True the grinding wheel frequently with a sharp diamond point tool to maintain a free cutting action.

(7) Be sure that the work centers are clean and that the headstock and tailstock centers are true and in alinement.

(8) Do not crowd the work onto the wheel. It will not cut any faster, but will heat the work and cause excessive wheel wear.

11. Lubricants.—*a.* A cooling liquid usually should be supplied at the point of contact between the wheel and the work. It serves the following purposes:

(1) Keeps the work and wheel cool.

(2) Washes the abrasive away from the wheel and work.

(3) Enables the wheel to produce a better finish.

b. Clear water may be used as a lubricant, but various compounds containing alkali are usually added to improve its lubricating quality and prevent rusting of the machine and work.

c. A lubricant that is often used for all metals except aluminum and its alloys consists of a solution of approximately ¼ pound of sodium carbonate (sal soda) dissolved in 1 gallon of water. A small amount of medium grade machine oil may also be added to form an emulsion. Another very good lubricant for grinding practically all metals, except aluminum and its alloys, consists of a solution containing 5 pounds soft soap, 2 pounds sodium carbonate (sal soda), ⅔ gallon lard oil, 1 dram creosote, and 1 gallon water. The soap is dissolved in boiling water and the remaining ingredients added while solution is still boiling. Three gallons of water are added to each gallon of this solution before use. For grinding aluminum, a mixture of equal parts of water and kerosene is used for rough work while straight kerosene is used for finishing. There are also many ready-mixed, commercial grinding lubricants that give very good results.

12. Speeds and feeds.—*a.* In grinding, the speed of the wheel is measured in surface feet per minute (f. p. m.) and not in revolutions per minute. The various factors which govern the speed of a grinding wheel are as follows:

(1) Safety.
(2) Condition of the machine.
(3) Material being ground.
(4) Finish desired.
(5) Type of grinding wheel.

b. The speed with which a grinding wheel revolves is very important as too slow a speed will result in waste of abrasive, whereas an excessive speed will cause hard grinding action and create danger of glazing.

c. A grinding wheel should always be operated at the speed recommended by the manufacturer. This information is found on a small tag attached to the wheel. Under no circumstances should a wheel be operated at a greater speed than that recommended due to the danger involved. Tables giving the speed of wheels may be used when the manufacturer's recommendations are not available. Wheels are usually operated at a peripheral speed of from 4,500 to 6,000 feet per minute. While speeds as high as 10,000 f. p. m. are not uncommon for certain classes of work, they are considerably above those used for the average job. As wheels wear, the speed in f. p. m. becomes less and the r. p. m. should therefore be increased accordingly to maintain the proper peripheral speed. The following formulas as well as tables III and IV will be useful in calculating the speeds of grinding wheels in both f. p. m. and r. p. m.

Formulas: $0.2618 \times \text{diameter of wheel} \times \text{r. p. m.} = \text{f. p. m.}$

$$\frac{\text{f. p. m.}}{0.2618 \times \text{diameter of wheel}} = \text{r. p. m.}$$

TABLE III.—*Recommended peripheral speeds for standard types of grinding wheels*

Wheels illustrated in fig. 15	Vitrified and silicate bonds (f. p. m.)			Organic bonds (f. p. m.)		
	Soft	Medium	Hard	Soft	Medium	Hard
Straight wheels (A)	5, 500	6, 000	6, 500	6, 500	8, 000	9, 500
Taper wheels (D)	5, 500	6, 000	6, 500	6, 500	8, 000	9, 500
Recessed wheels (E) and (F)	5, 500	6, 000	6, 500	6, 500	8, 000	9, 500
Cylinder wheels (C)	4, 500	5, 500	6, 000	6, 000	8, 000	9, 500
Dish and flaring cup wheels (H) and (I)	4, 500	5, 500	6, 000	6, 000	8, 000	9, 500
Straight cup wheels (F)	4, 500	5, 000	5, 500	6, 000	7, 500	9, 000
Cut-off wheels (B)	-------	-------	-------	-------	10, 000	12, 000

TABLE IV.—*Recommended rotational speeds for various wheel diameters*

Diameter of wheel (inches)	R. p. m. for s. f. s. 4,000	R. p. m. for s. f. s. 5,000	R. p. m. for s. f. s. 5,500	R. p. m. for s. f. s. 6,000	R. p. m. for s. f. s. 6,500
1	15, 279	19, 079	21, 000	22, 918	24, 828
2	7, 639	9, 549	10, 500	11, 459	12, 414
3	5, 093	6, 366	7, 350	7, 369	8, 276
4	3, 820	4, 775	5, 250	5, 730	6, 207
5	3, 056	3, 820	4, 200	4, 584	4, 966
6	2, 546	3, 183	3, 500	3, 820	4, 138
7	2, 183	2, 728	3, 000	3, 274	3, 547
8	1, 910	2, 387	2, 600	2, 865	3, 103
10	1, 528	1, 910	2, 100	2, 292	2, 483
12	1, 273	1, 592	1, 750	1, 910	2, 069
14	1, 093	1, 364	1, 500	1, 637	1, 773
16	955	1, 194	1, 300	1, 432	1, 552
18	849	1, 061	1, 150	1, 273	1, 379

d. The peripheral speed of work being ground should be proportional to the grade and speed of the wheel as well as to the diameter of work and finish desired. A high work speed tends to wear the wheel faster than a low work speed and the average will vary from 20 to 60 f. p. m.

e. The table or traverse speed should be proportional to the width of the wheel face and the finish desired. In general, the narrower the face of the wheel the slower the traverse speed and the faster the work speed. The following general rules may be used:

(1) For roughing, the table should traverse about three-fourths the width of the wheel per revolution of the work.

(2) For an average finish, the table should traverse one-third to one-half the width of the wheel per revolution of the work.

(3) For the finish, the table should traverse one-fourth to one-third the width of the wheel per revolution of the work.

(4) For wheels less than 1 inch in width, the table traverse speed should be reduced about one-half.

13. Grinding principles.—*a.* When grinding several pieces of duplicate work, it is good practice to rough grind all pieces to within 0.0005 to 0.001 inch of the desired size before finishing. The wheel can then be changed to a finer grain or the same wheel may be trued and the finishing cuts taken. This last procedure eliminates repeated changing of the wheel.

b. For average work, a true, smooth surface is sufficient. A force fit need not have a perfectly smooth finish but must be ground to size. Gages, tools, etc., must be given a fine, accurate finish to exact size and

this is accomplished by taking light cuts, using a slow feed. A true wheel and an adequate amount of lubricant are also necessary.

c. A wide-faced wheel and a coarse feed must be used to remove material rapidly and the wheel face should extend from one-fourth to one-half its width beyond the end of the work or recess. A narrow-faced wheel should be used for grinding close to a square shoulder as well as for grinding a recess.

d. For roughing, a cut of 0.001 inch to 0.003 inch in depth is used for each stroke depending upon the size of the machine. For finishing, the depth of cut should be 0.00005 inch to 0.0005 inch. An indication of the depth of cut is given by the volume of sparks thrown off while an uneven amount of sparks indicates that the work or wheel is out of true.

e. It is very important in the production of accurate work to keep the wheel property dressed. The object of dressing the cutting face of a wheel is to sharpen the cutting grains so that they will cut freely without generating undue heat. The wheel is trued to a certain extent by the action of the dresser, although this truing is not sufficient for precision grinding. For pedestal grinders, or in grinders where the wheel is to be used for off-hand grinding, additional truing is unnecessary.

f. Truing a grinding wheel gives it a clean face and produces a surface that revolves concentrically with the wheel spindle. It is done when precision work is desired although all grinding wheels should be trued directly after mounting. There are several approved methods of truing a grinding wheel. A diamond or diamo-carbo point held as shown in figure 19 is generally used for the first truing operation after

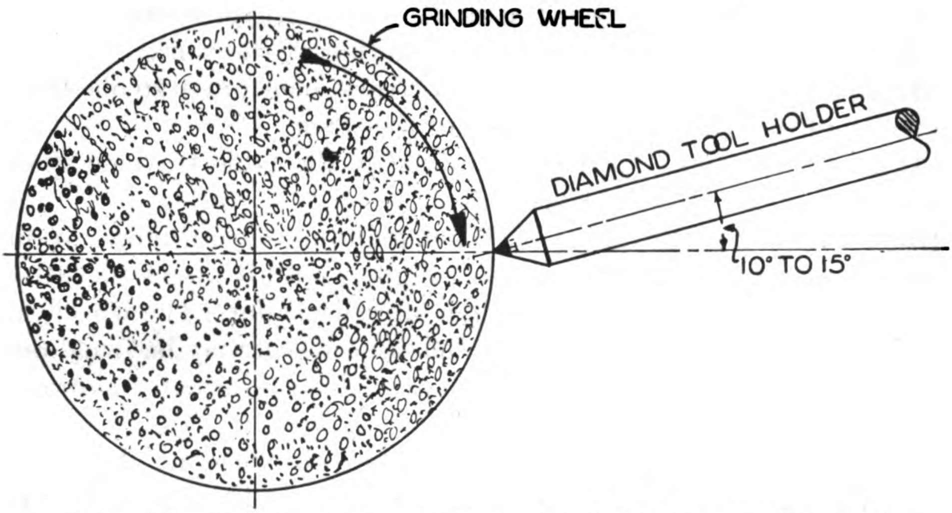


FIGURE 19.—Correct application of diamond point for truing grinding wheel.

the wheel is mounted. Abrasive sticks are often used in subsequent operations and are available in two shapes; a square stick for use in hand truing and a round one when it is to be held mechanically. These sticks are especially suited for truing wheels when grinding reamers, milling cutters, and other miscellaneous cutting tools. They are used extensively in the toolroom for forming wheels to various patterns for profile grinding and are also valuable for dressing or truing various shaped wheels of thin cross section. When abrasive sticks are not available, a broken piece of grinding wheel may be used as a substitute. For accurate truing of a wheel, the truing device should be held on the center of wheel, never above. The following points are very important in the correct truing of grinding wheels:

(1) The truing device should be held by mechanical means except in unavoidable cases.

(2) The diamond tool should be set at an angle, pointing in the same direction as the grinding wheel travel to prevent gouging the wheel face.

(3) As the diamond wears, the diamond should be turned to insure a sharp point at all times. Dull diamonds crush and glaze the wheel face, dulling the cutting points and reducing the efficiency of the wheel.

(4) The grinding wheel face usually wears more on the edges, leaving a high spot in the center. For this reason, when starting to true a wheel, both the wheel and table should be in motion before applying the diamond point. The diamond should be fed lightly into the wheel until the sound of the diamond on the wheel indicates that it is perfectly true. The rapidity with which the diamond is moved across the wheel face depends upon the grain and grade of the wheel and the finish desired.

(5) A slow feed gives a high finish, but if too slow, will glaze the wheel; a fast feed produces a free-cutting wheel, but if too fast, will leave "diamond marks" on the wheel. The correct speed can only be determined by trial and a steady, uniform rate should be maintained during any one pass. Wheels may be dressed either wet or dry but the operation should always be carried on under the same conditions as the grinding operation.

(6) When it is desired to true a wheel for radial grinding, the radius-grinding attachment should be used. A special diamond holder is bolted to the attachment as shown in figure 20. It is important that the diamond point be in line with the surface shown in figure 7 (2), and that the center of the wheel be at the same height as work centers.

The slide is next set to the required radius. Two methods can be used for truing, and are as follows:

(*a*) The table may be locked longitudinally with the wheel running at right angles to it. The attachment is then swiveled and the wheel fed to it with the cross feed.

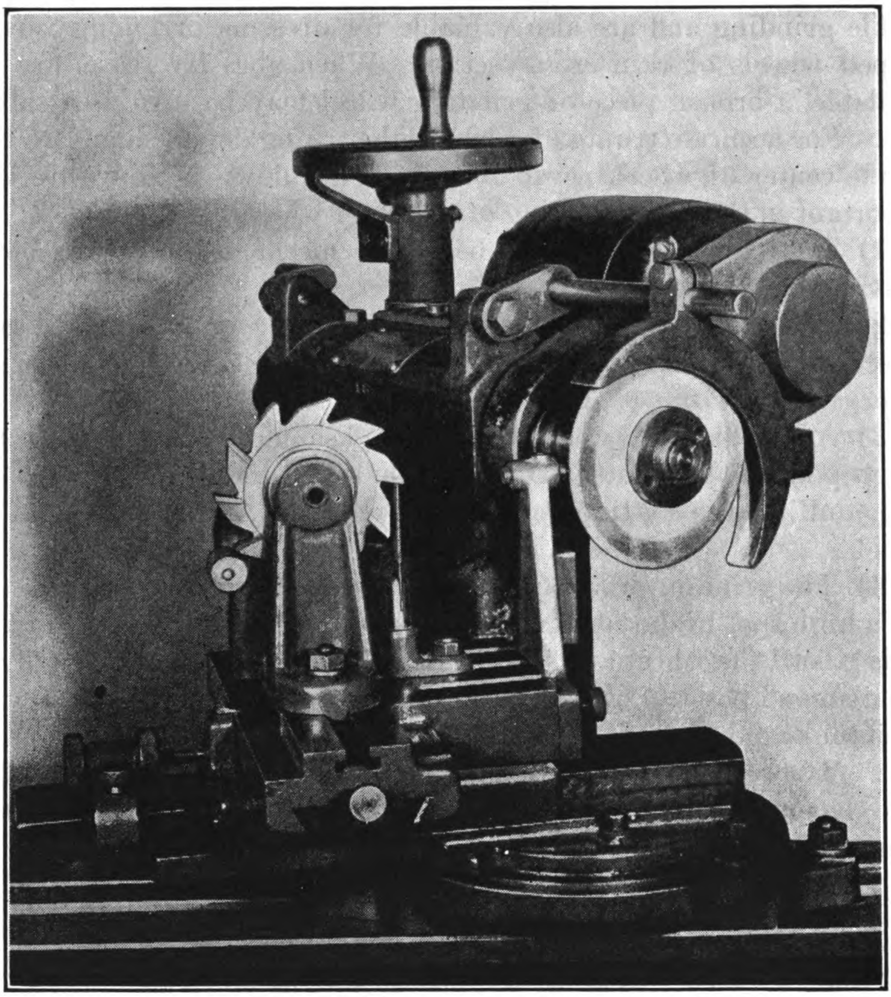


FIGURE 20.—Radial truing of a grinding wheel.

(*b*) The wheel may be set parallel with the table and the diamond brought into line with it and fed forward with the longitudinal table feed while being swiveled.

(7) After the wheel is properly trued, the table should be locked and the diamond point removed. Where it is necessary to remove a large quantity of material from the wheel, an ordinary wheel dresser should be used to reduce the bulk of the abrasive and a diamond used only for the final truing operation.

(8) The proper methods of doing angular and radius truing are clearly shown in figures 9 and 10.

g. After the work has been set up, the wheel should be moved back away from the table so that it clears the headstock and tailstock. The dogs are then set in their approximate position and the machine started. The transverse feed is next engaged and while the machine is in motion the dogs are reset to the exact position. The wheel may then be slowly brought into contact with work and the grinding operation accomplished.

h. When the spaces between the abrasive grains of a wheel become filled with particles of the material being ground, the wheel is referred

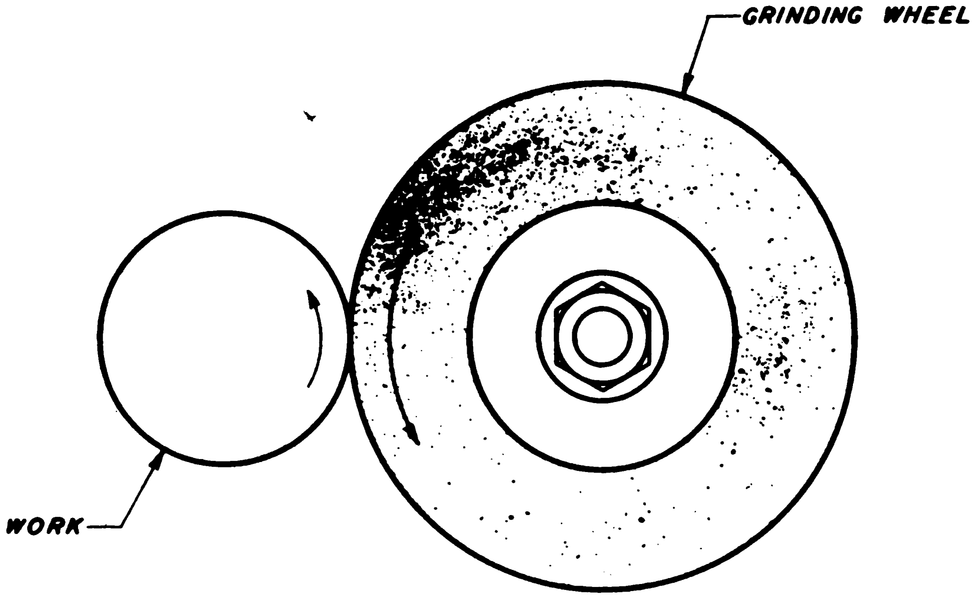


FIGURE 21.—Direction of rotation of wheel and work for external grinding.

to as being loaded. A dry wheel will become loaded quicker than one on which lubricant is being used. Loading is also aggravated by the use of too fine a grain, too fast a wheel speed, or too slow a work speed.

14. Cylindrical grinding.—*a.* Cylindrical grinding may be done either with the work set up between centers, held in a chuck and supported by a center rest, held on live center and supported by a center rest, or clamped to the faceplate. Generally the rotation of the wheel and work should be in opposite directions, as shown in figure 21.

b. When work is held between centers, the use of two dead centers is preferable as this method eliminates any error that may be caused by the wear in the spindle bearings of the machine. Before starting

a grinding operation, the centers should be checked for accuracy and alinement and corrected, if necessary, in the following manner:

(1) To grind centers—

(*a*) Remove both headstock and tailstock centers.

(*b*) Clean out headstock and tailstock spindles with a rag or waste.

(*c*) Loosen clamp nuts and swivel headstock to a 30° angle.

(*d*) Clean off tailstock center and insert in headstock spindle.

(*e*) True grinding wheel.

(*f*) With center and wheel revolving in opposite directions, slowly bring center in contact with surface of wheel.

(*g*) Direct lubricant to flow on wheel and center.

(*h*) Grind to a 60° included angle.

(*i*) Check for accuracy.

(*j*) Knock out tailstock center, clean and insert headstock center in spindle and repeat the above operations. Do not remove headstock center after grinding.

(2) There are several methods that may be used in alining centers, each of which is outlined below.

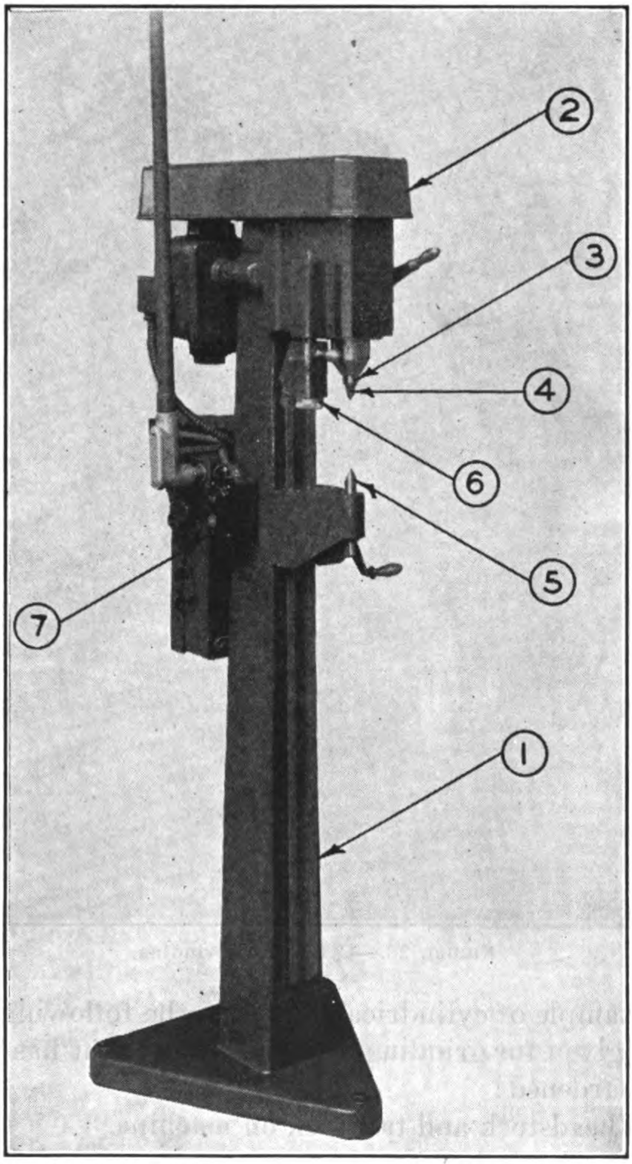
(*a*) Place the work that is to be ground between centers and grind until a true cylindrical surface is produced. Check with micrometers at points along the circumference. Any difference in diameter may be corrected by swiveling the table.

(*b*) Place test bar between centers and install the dial indicator on head of machine. Bring test bar up to make contact with dial point. Note reading on dial. Raise contact point off work and move table so that opposite end of test bar makes contact with dial point. Any difference in the dial reading may be corrected by loosening clamping nuts on table and swiveling table to the right or left. When centers are in line, draw up on clamp nuts to lock the table.

(*c*) Take a piece of material the same length as the article to be ground and use it for the piece on which to make the test grinds. When this method is used, proceed as in (*a*) above.

c. Before placing work between centers, be sure that the centers are clean. The center holes should be smooth and at a 60° angle. The cleaning can be done in a small lathe, drill press, or center lapping machine. If a drill press or lathe is used, a piece of hard wood with one end turned or filed to a 60° angle is held in the chuck. Grinding compound is applied to the wooden point and the work center lapped until smooth. When using the center lapping machine, an abrasive stick trued to a 60° angle is used.

A typical center lapping machine is shown in figure 22. Like grinding wheels, the abrasive sticks can be obtained in any grain size and bond. Generally a 60- to 80-grain stick gives the best results. Work to be ground is driven between centers by dogs attached to the driving plate or caused to turn by self-driving centers set in the headstock.



1. Column and base.
2. Change speed box.
3. Chuck.
4. Abrasive stick.
5. Adjustable center.
6. Truing device.
7. Switch.

FIGURE 22.—Center lapping machine.

d. A typical cylindrical grinding set-up is shown in figure 23 which also illustrates an arrangement for using a coolant on the work. The piece of work in position on the machine is a plain bushing being ground on an arbor, revolving on dead centers. Power table feed is used for moving the work past the wheel.

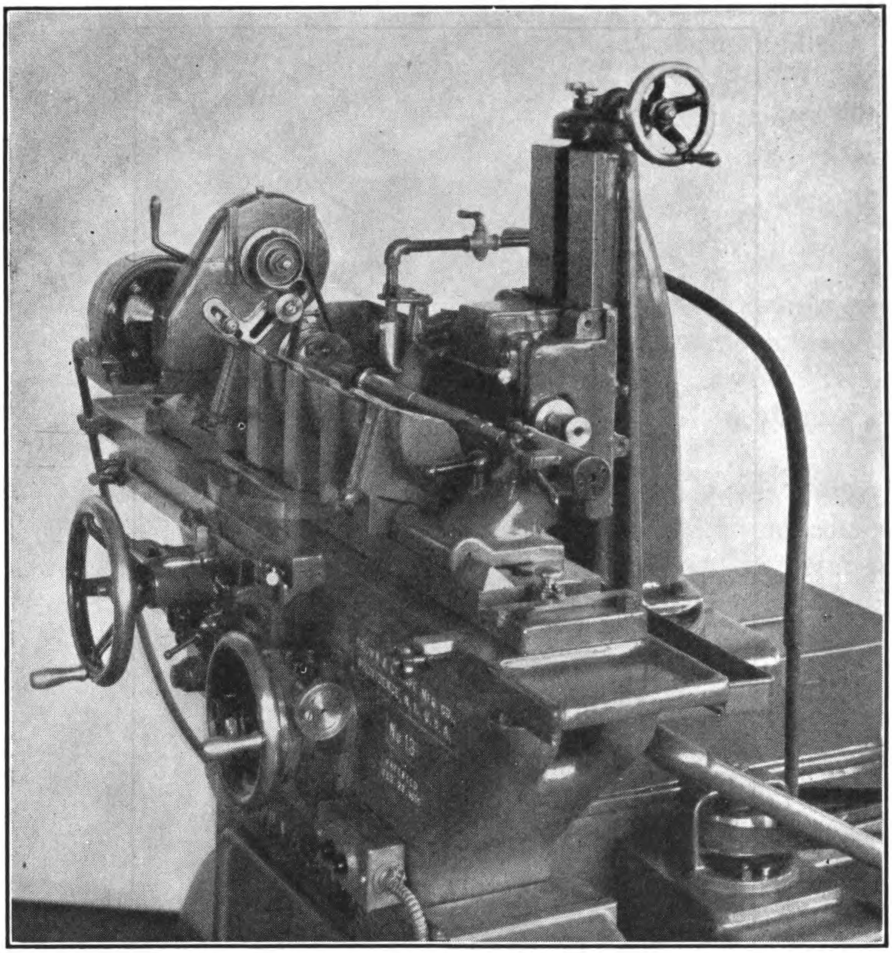


FIGURE 23.—Cylindrical grinding.

e. As an example of cylindrical grinding, the following step-by-step procedure is given for grinding a straight shaft that has been roughly turned and hardened:

(1) Place headstock and tailstock on machine.

(2) Check and grind centers if necessary.

(3) Check and aline centers if necessary.

(4) Clean work centers.

(5) Place a wheel of the proper grade, grain, and structure on wheel spindle.

(6) Place water guards around wheel.
(7) True wheel.
(8) Place driving dog on one end of shaft.
(9) Place shaft between two dead centers.
(10) Set reversing dogs and table speed.
(11) Grind and check for accuracy.

15. Conical grinding.—*a.* Machine work involving the grinding of tapers is known as conical grinding. Tapers may be of any length and either external or internal. Work of this nature may be held either between centers or in a chuck.

b. Figure 24 shows a set-up for taper grinding. The article being ground in this case is held between two dead centers and driven by a dog. The table is swiveled by loosening two cap screws at each end and a nut in the center. A graduated arc on the front of the table gives the approximate setting. Care should be taken to have the work center and wheel center at the same height when setting up the machine. This can be checked either by means of a surface gage as shown in figure 25, or by setting the wheel slide to the line on the wheel slide upright as shown in figure 1 (21).

c. The grinding of a long machine center is shown in figure 26. The work is held on the headstock center of the machine by means of rawhide lacing passed around the driving dog and tied to the faceplate. The outer end of the center is supported in the center rest and the table is set at the required angle. Like other taper grinding, the work and wheel center must be carefully alined. The grinding of an inside taper is shown in figure 27. The work is mounted in a chuck, and in this case as in other taper grinding, the work and wheel centers must be at the same height.

d. As an example of conical grinding, the following step by step procedure is given for grinding a No. 3 Morse taper plug gage:

(1) Place headstock and tailstock on machine.
(2) Check and grind centers if necessary.
(3) Check and aline centers if necessary.
(4) Clean work centers.
(5) Place a wheel of the proper grade, grain, and structure on the wheel spindle.
(6) Place water guards around wheel.
(7) True wheel.
(8) Swivel table to correct angle.
(9) After work has been placed between centers set reversing dogs and table speed.
(10) Grind and check for accuracy.

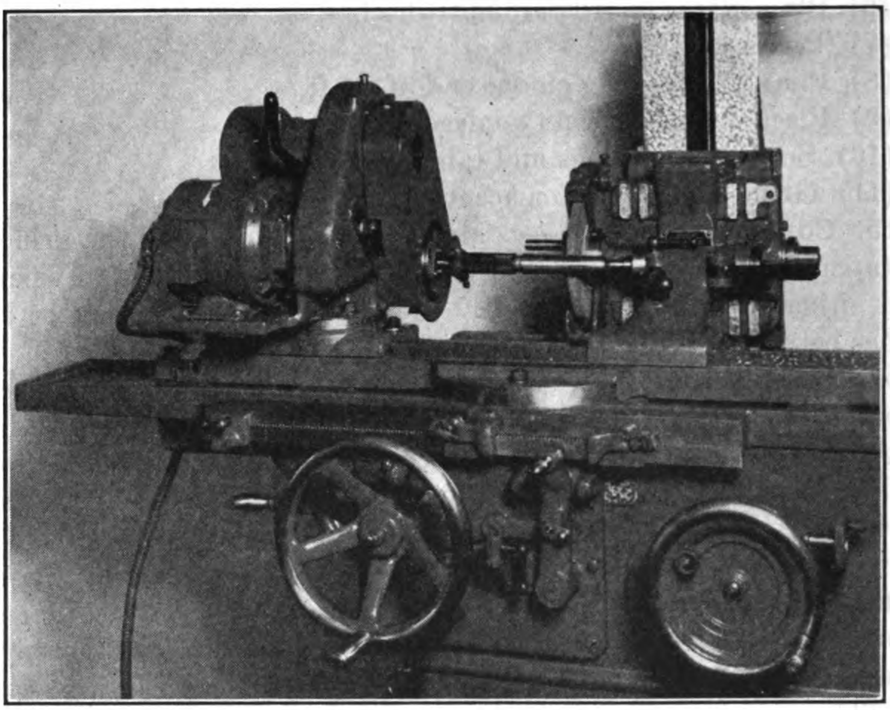


FIGURE 24.—Taper grinding.

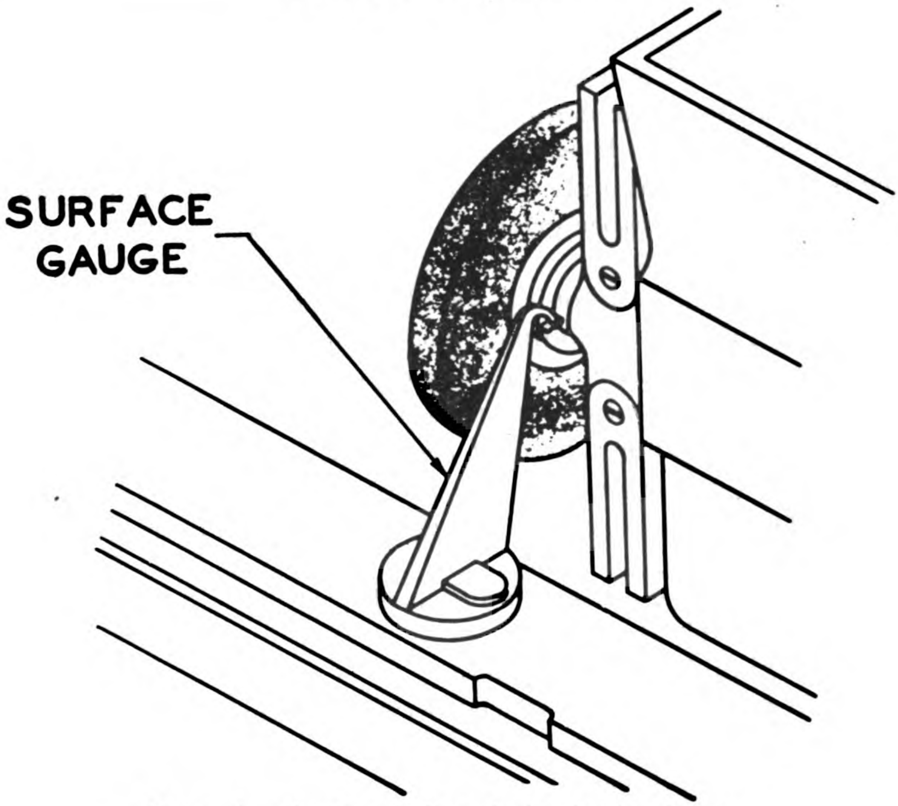


FIGURE 25.—Setting grinding wheel to height of center.

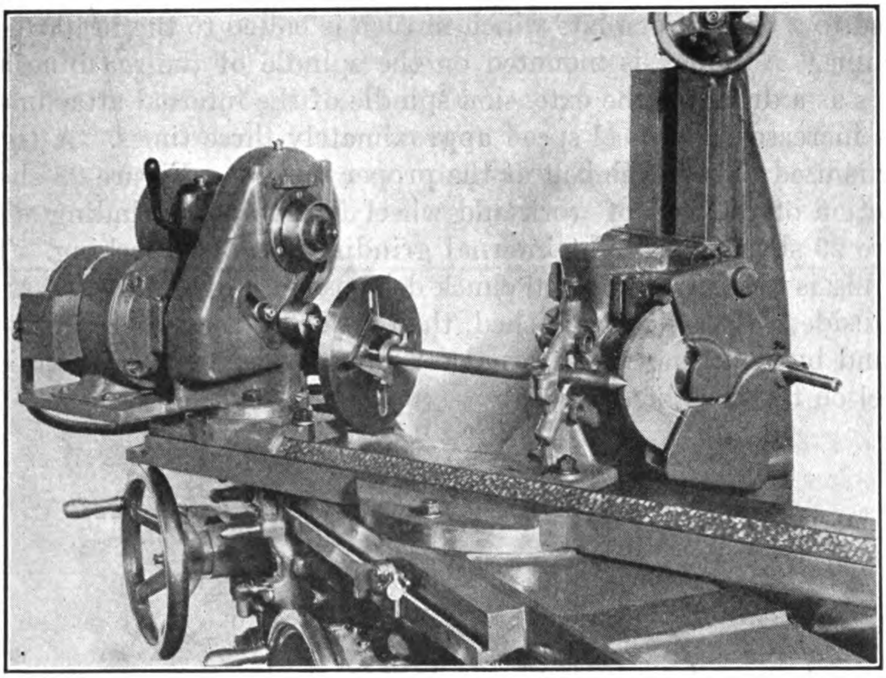


FIGURE 26.—Grinding long machine center.

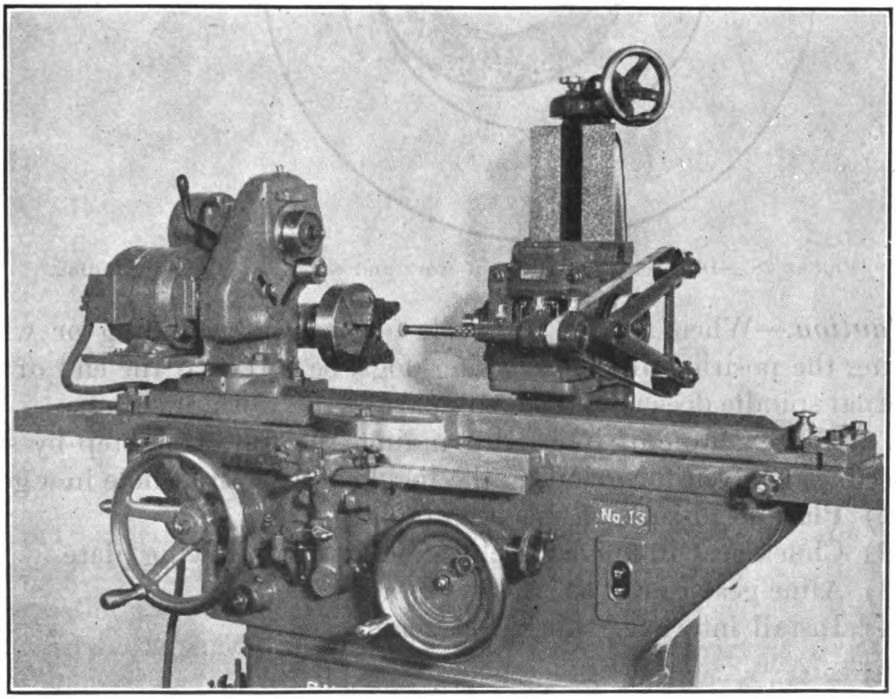


FIGURE 27.—Grinding inside taper.

16. Internal grinding.—*a.* The internal grinding attachment is bolted to a bracket or plate which in turn is bolted to the head of the machine. A pulley is mounted on the spindle of the machine and serves as a drive for the extension spindle of the internal attachment. This increases the wheel speed approximately three times. A tightener is used to keep the belt at the proper tension. Figure 28 shows direction of rotation of work and wheel for internal grinding while figure 29 shows a straight internal grinding job on a bushing. The bushing is held in a universal chuck driven by the live pulley. After the inside bore has been finished, the outside of the bushing may be ground by removing the internal attachment and placing a straight wheel on the machine.

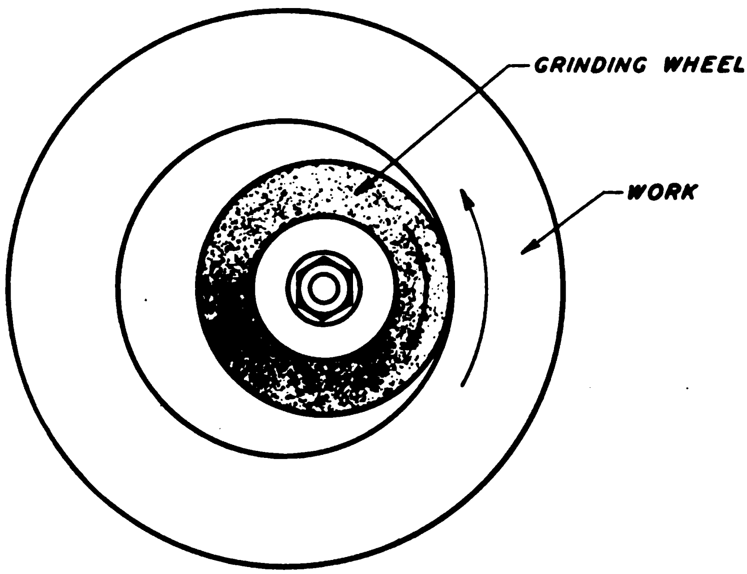


FIGURE 28.—Direction of rotation of work and wheel for internal grinding.

Caution.—When setting up work for internal grinding or when setting the position of the reversing dogs, be sure that the end of the internal spindle does not strike any part of the work or set-up.

b. As an example of internal grinding, the following step by step procedure is given for grinding the inside of a straight hole in a gear.

(1) Place headstock on machine table.
(2) Chuck gear in universal chuck or clamp to driving plate.
(3) Aline gear to run as true as possible.
(4) Install internal grinding attachment.

(5) Place a wheel of the proper grade, grain, and structure on wheel spindle.

(6) True wheel.

(7) Set reversing dogs.

(8) Grind and check for accuracy.

17. Surface grinding.—*a.* Surface grinding consists of the grinding of flat surfaces on either hardened or unhardened stock.

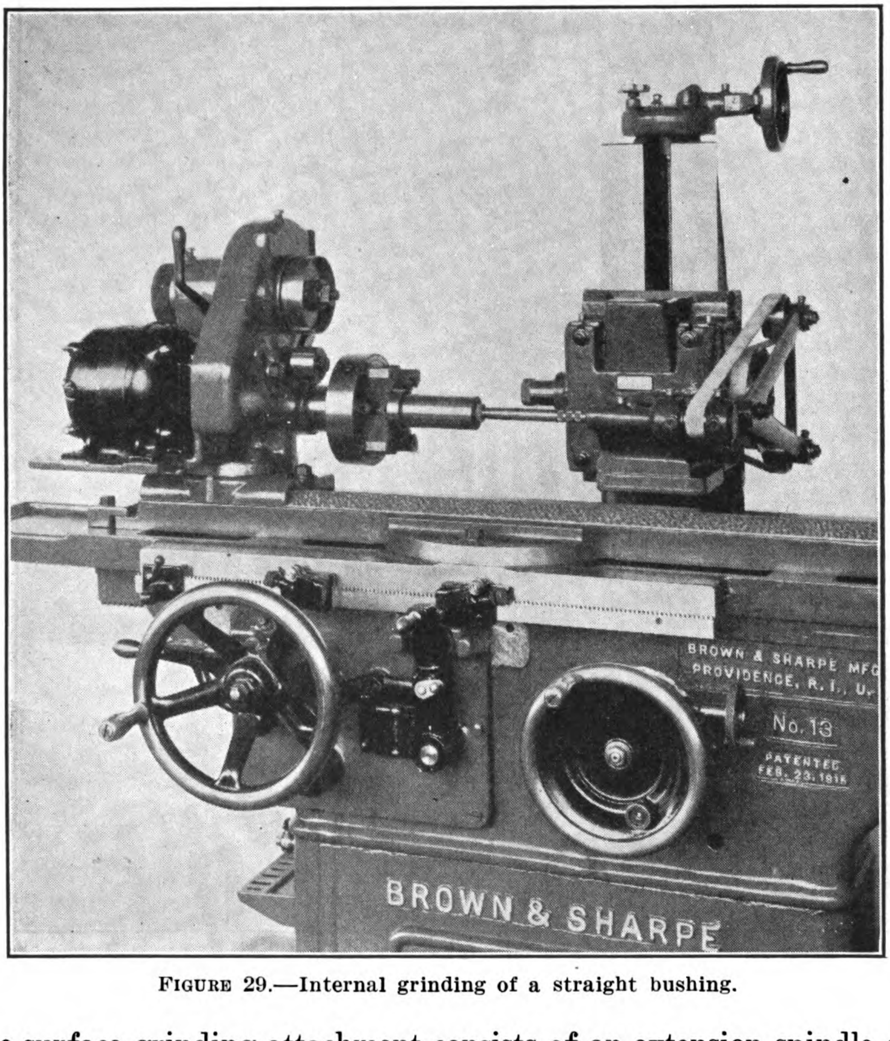


FIGURE 29.—Internal grinding of a straight bushing.

The surface grinding attachment consists of an extension spindle and support arm. The work may be held in a vise, clamped to a surface plate on the machine table, or held on a magnetic chuck. A typical surface grinding set-up is shown in figure 30. When using a vise in connection with surface grinding, care must be taken to avoid spring-

ing the work out of shape and the vise and table must be perfectly clean before the set-up is made. If work is held by clamps, care must be used to provide some means of support under each clamp. Where work is being held by a magnetic chuck, the chuck surface and work should be thoroughly cleaned.

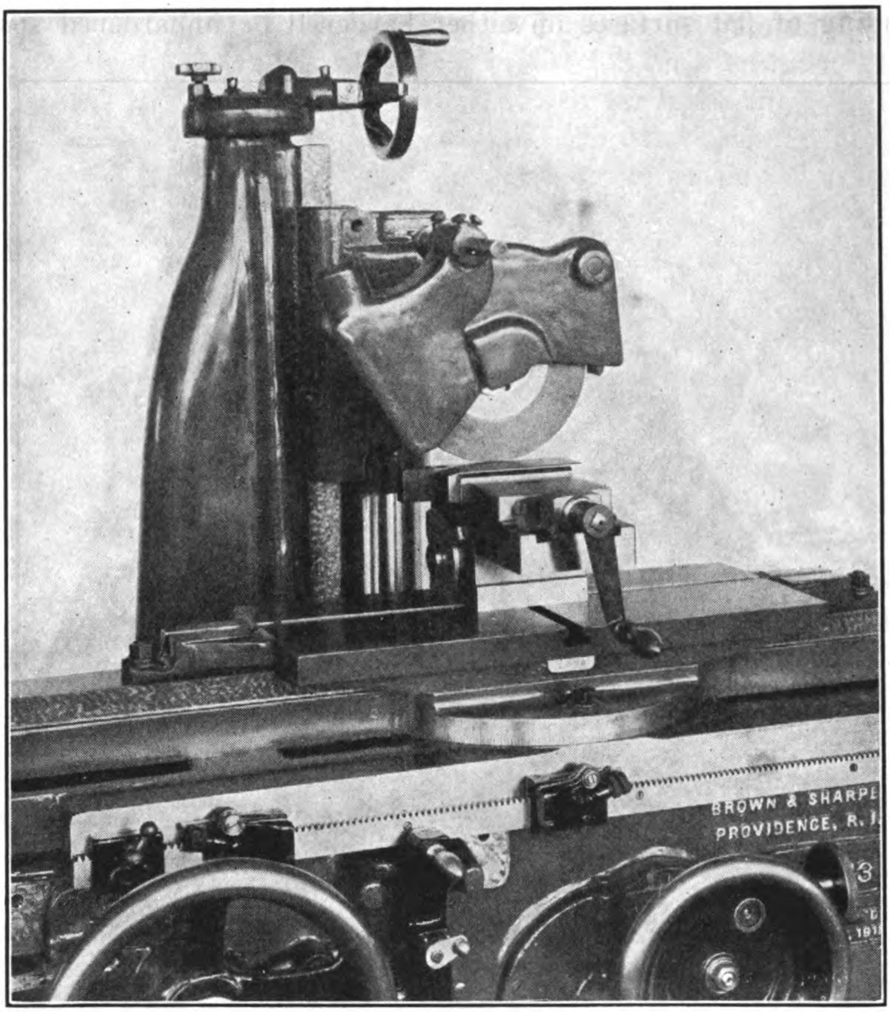


FIGURE 30.—Surface grinding.

b. (1) There are two classes of surface grinding machines in common use and may be defined as follows:

(*a*) The planer type in which the work table reciprocates.

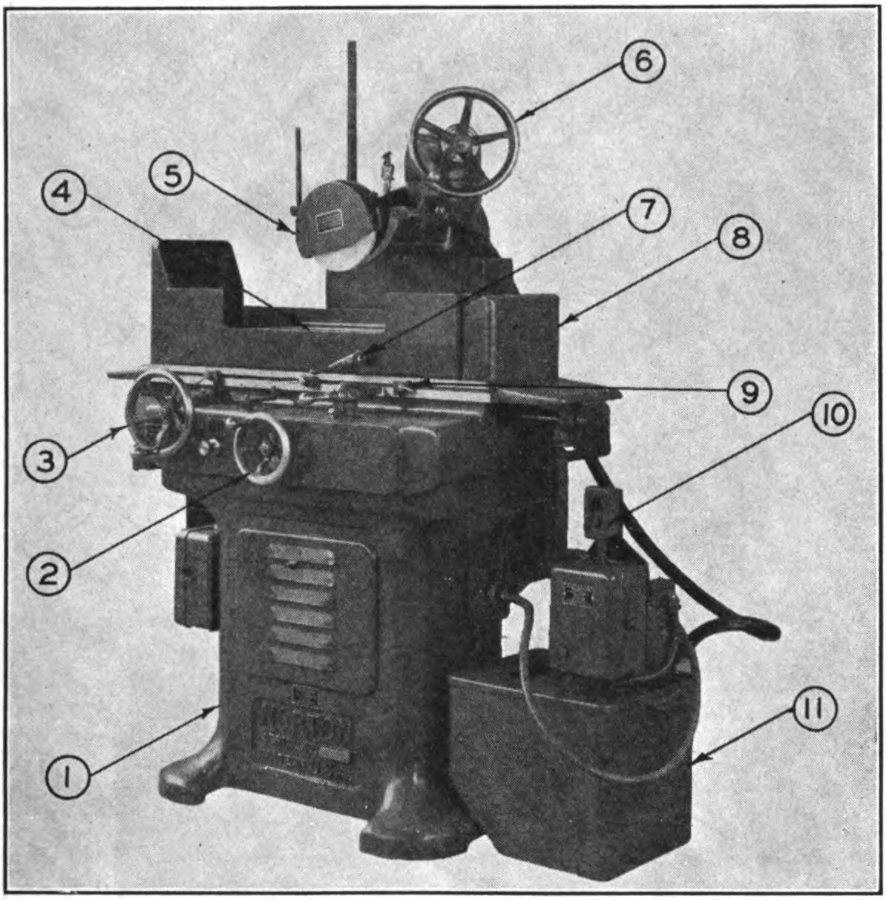
(*b*) The rotor type in which the work table revolves.

(2) Both classes may have either a horizontal or vertical spindle. The horizontal spindle type is shown in figure 31 and the vertical type in figure 32.

c. As an example of surface grinding, the following step by step procedure is given for grinding a parallel block:

(1) Place surface grinding attachment on grinding machine.

(2) Swivel either grinder head or table so that wheel and table are parallel.



1. Base.
2. Cross feed handwheel.
3. Table traverse handwheel.
4. Magnetic chuck.
5. Spindle wheel and guard.
6. Vertical feed handwheel.
7. Magnetic chuck lever.
8. Water guard.
9. Reverse dogs.
10. Switch.
11. Wet grinding attachment.

FIGURE 31.—Surface grinder with horizontal spindle.

(3) Place a wheel of the proper grade, grain, and structure on wheel spindle.

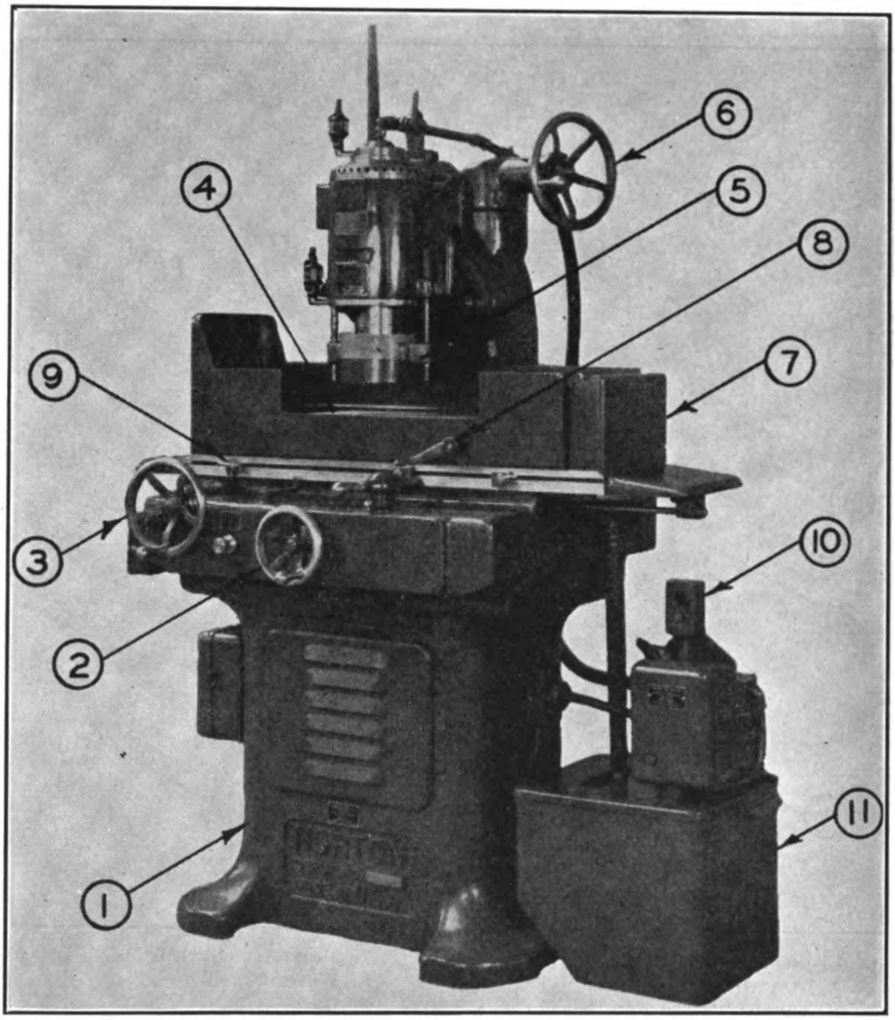
(4) Place guard on wheel.

(5) True wheel.

(6) Place magnetic chuck on table.

(7) Place parallel on chuck, set reversing dogs, and proceed with grinding operation.

18. Thread grinding.—*a.* In the manufacture of aircraft engine parts, gages, and other articles where strength and accuracy are of



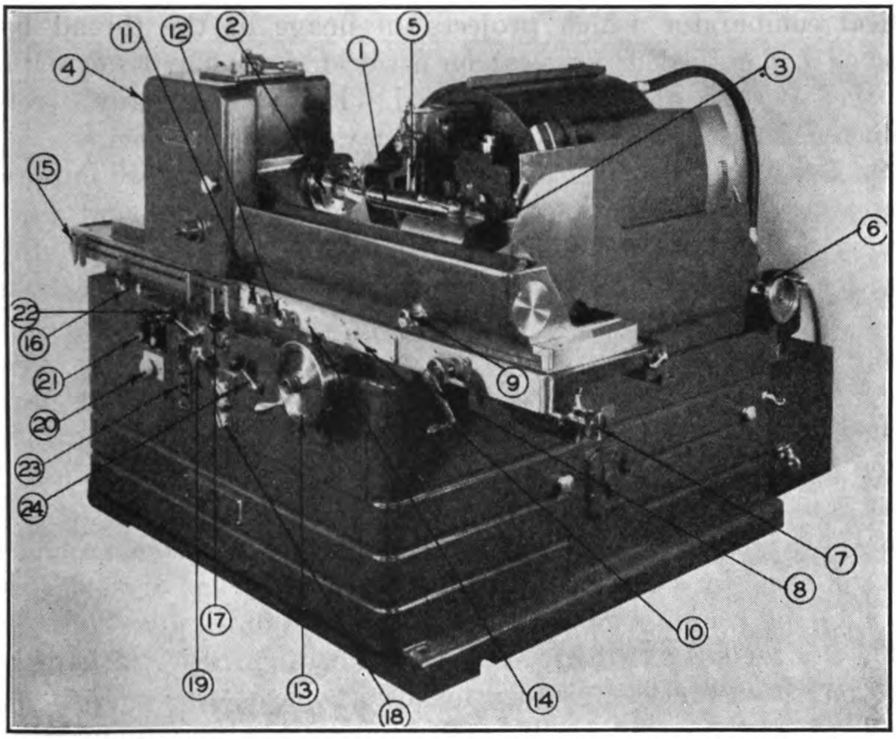
1. Base.
2. Cross feed handwheel.
3. Table traverse handwheel.
4. Magnetic chuck.
5. Wheel and guard.
6. Vertical feed handwheel.
7. Water guard.
8. Magnetic chuck lever.
9. Reverse dogs.
10. Switch.
11. Wet grinding attachment.

FIGURE 32.—Surface grinder with vertical spindle.

major importance, threads are ground rather than cut on the solid stock. A fully automatic, precision thread-grinding machine is shown in figure 33. The table of this machine has a hydraulic backlash compensating mechanism operating in conjunction with the lead

screw. A wheel-truing device is actuated hydraulically and filtered lubricant is pumped to all important moving parts of the machine.

b. The grinder will produce continuous internal or external right- or left-hand threads and is also readily adaptable for multiple



1. Work to be threaded.
2. Work spindle.
3. Tailstock.
4. Hydraulic motor housing.
5. Grinding wheel and lubricant nozzles.
6. Handwheel to operate wheel cradle.
7. Hydraulic backlash compensator.
8. Work positioning knob.
9. Adjusting screw knob.
10. Lead compensator.
11. Lead error adjusting knob.
12. Lead error adjusting knob lock.
13. Cross feed handwheel.
14. Automatic control of cross feed.
15. Adjusting dogs.
16., 17., 18., 19. Table controls.
20. Emergency button, stopping entire machine.
21. Switches for wheel and hydraulic pump.
22. Knob controlling truing device.
23. Hydraulic controlled truing device.
24. Hand-control lever, dresser slide.

FIGURE 33.—Nomenclature for thread grinding machine.

thread grinding. The working range of the machine may be outlined as follows:

(1) Any pitch from 1 to 40 per inch in the U. S. S., sharp "V," 29° Acme and modified buttress threads can be ground.

(2) Threads $\frac{5}{16}$ inch to 8 inches outside diameter and 1 inch to 8 inches inside diameter can be ground.

(3) Threads can be ground on heat-treated solid blanks, or threads that have been roughed before heat treatment can be finish ground.

(4) Tolerances can be held to within 0.0002 inch per inch of thread.

c. A fixture for checking the accuracy of the ground threads may be obtained for most thread-grinding machines and consists of an optical comparator which projects an image of the thread being checked (magnified 62.5 times) on a screen for comparison with an enlarged outline of a perfect thread. In this way, any error in diameter, lead, form, or uniformity may readily be seen.

19. Gear grinding.—*a.* Where speed and strength are important factors, external and internal spur gears may be ground for accuracy. There are two types of gear grinders in general use. In the first, the gear tooth passes between and under two grinding wheels and in this way is ground on both sides at the same time. The second type has a single wheel trued to the shape of the gear tooth. As this wheel passes over the gear, a side of two adjacent teeth are ground at the same time. The single-wheel machine may be used for grinding either internal or external gear teeth whereas the double-wheel machine is used on external work only.

b. When grinding gears, several rough cuts are taken around the gear followed by a light finishing cut. The wheel is dressed several times during rough grinding and also prior to finish grinding.

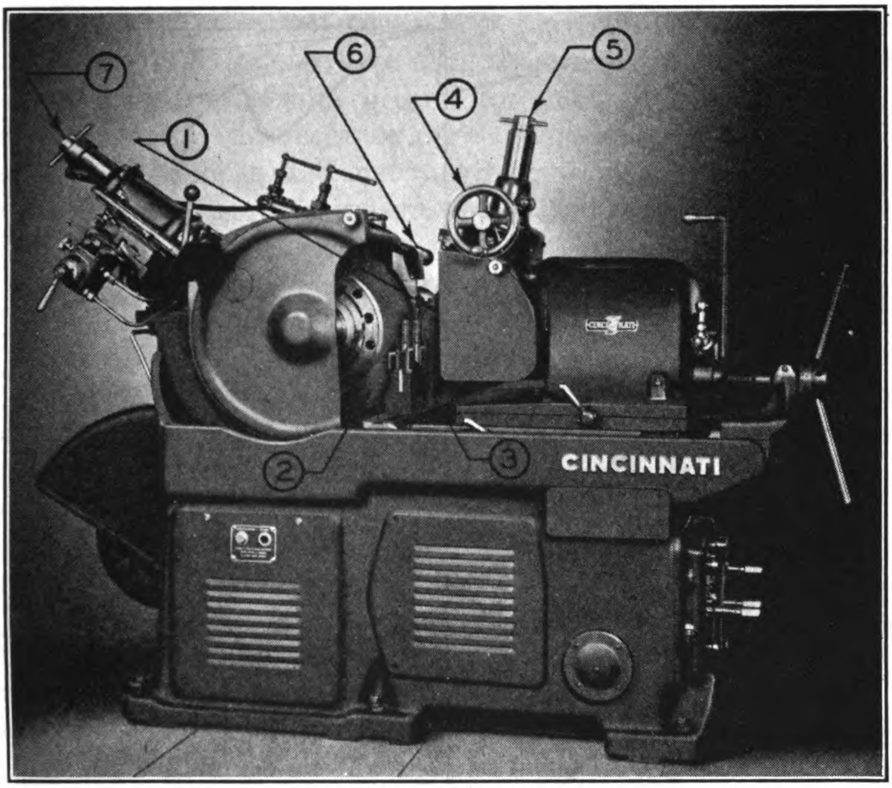
20. Centerless grinding.—*a.* The wide range of work that can be done on the centerless grinder makes it one of the most popular of all grinding machines. This machine (fig. 34) can grind articles from 0.015 inch in diameter and 2 inches long to 4 inches in diameter and 18 feet long.

b. There are two principal methods of centerless grinding. The first is known as the "through-feed" method where the work passes along the line of its axis from one side of the machine to the other, entering as a rough blank and being discharged in its finished form. The second or "in-feed" method is applied to shoulder and other similar work; in this method, the work is ejecting at the same point at which it is fed into the machine.

c. The grinding wheel serves solely to grind off the material, while the regulating wheel controls the speed of rotation of the work as well as the longitudinal feed movement. Between the two wheels are the work rest and guides for through-feed, and the work-rest ejector for in-feed.

21. Tool and cutter grinding.—*a.* Tools and cutters are usually ground on universal grinding machines. This type of grinder is com-

pact and easily operated. By the use of attachments, all types of tools may be ground accurately and economically. Care must be exercised when grinding heat-treated tools to prevent them from becoming overheated as overheating will draw the temper of the metal and thereby ruin the tool.



1. Regulating wheel.
2. Grinding wheel.
3. Work support blade.
4. Regulating wheel truing device.
5. Micrometer dial for adjusting diamond truing device on regulating wheel.
6. Lubricant supply nozzle.
7. Micrometer dial for adjusting diamond truing device on grinding wheel.

FIGURE 34.—Centerless grinder.

b. Wheels used for grinding tools, such as cutters and reamers, should be of soft or medium grade and medium structure as fine-grain wheels cut slowly and tend to burn the teeth. For sharpening ordinary milling cutters, a 36- to 60-grain, ¼- to ⅝-inch wheel should be used. Cylindrical cutters and reamers may be ground with either a straight or cup wheel. The cup wheel grinds a flat land whereas the straight wheel gives the land a slight concavity. Form cutters are usually ground with a dish wheel.

c. When sharpening cutters and reamers, the clearance should always be taken into consideration. Clearance, or relief, on cutting tools is the amount of material removed from the top of the teeth back of the cutting edge. This clearance permits the teeth to clear the stock

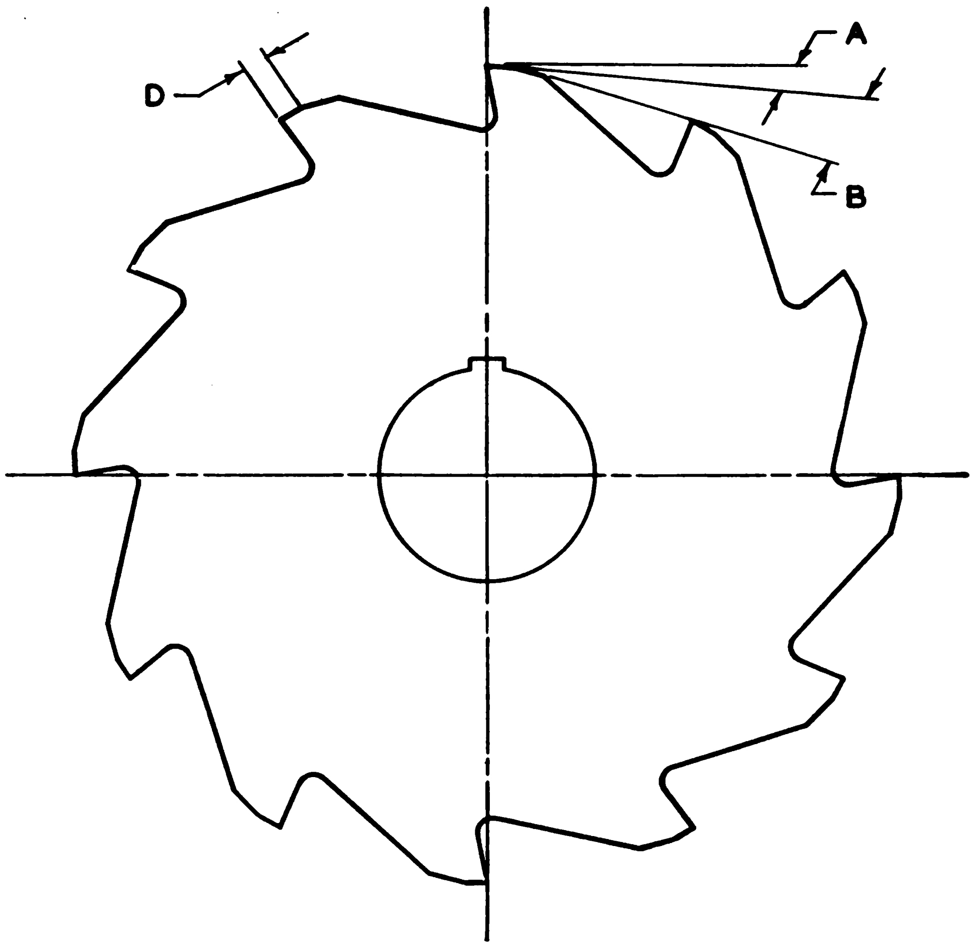


FIGURE 35.—Clearance angles for milling machines.

Material	Clearance angle A (degrees)	Clearance angle B (degrees)	Dimension D (inches)
Low carbon steel	5 to 7	30	1/32
High carbon steel and tool steel	3 to 5	30	1/32
Steel castings	5 to 7	30	1/32
Cast iron	4 to 7	30	1/32
Cast brass	10 to 12	30	1/32
Soft bronze (60 Brinell or less)	10 to 12	30	1/32
Medium bronze (60 to 90 Brinell)	6 to 7	30	1/32
Hard bronze (above 90 Brinell)	4 to 5	30	1/32
Copper	12 to 15	30	1/32
Aluminum	10 to 12	30	1/32

and not scrape over it after the cutting edge has done its work. It is very important that the cutting clearance is correct for if it is insufficient, the teeth will make a dragging cut, while if it is too great, the teeth will wear rapidly and are apt to chatter. Too much clearance, however, is less objectionable than too little. The angle of clearance depends upon the diameter of the cutters and the material that is to be machined. For example, cutters employed for soft materials like brass can stand more clearance than those used on steel or cast iron. The clearance must also be greater for small cutters than for large ones. In general, the clearance angle should be from 6° to 7° for cutters up to 3 inches in diameter and from 3° to 5° for cutters larger than 3 inches. The measurement of the clearance angles of a typical cutter is shown in figure 35 and the accompanying table gives recommended clearances for various types of work.

(1) The land, which is the narrow surface shown at (D), figure 35 (immediately behind the cutting edge), should be from 1/32 to 1/16 inch wide, depending upon the type and size of the cutter. As a result of repeated grinding, the land may become so wide as to cause the heel of the tooth to drag on the work. To control this width, a secondary clearance shown at (B), figure 35 (usually between 20° and 30°) is ground. If the land becomes excessively wide, it may be necessary to grind the flute between the teeth.

(2) Reamers are ground with either one or two angles depending on their size, whereas formed cutters such as gear tooth cutters, fluting cutters, etc., are ground radially to maintain the same clearance. The clearance of the end teeth of end mills should be about 2° and grinding the teeth approximately 0.001 inch to 0.002 inch lower in the center than at the outside prevents the inner ends of the teeth from dragging on the work. This can be done by slightly off-setting the swivel on the universal head from the 90° position. If the clearance of the cutter is too great, vibration is likely to occur in operation, and if too small, the cutter tends to leave a rough surface.

d. Cutters and reamers may be ground with the grinding wheel rotation either toward or away from the cutting edge as shown in figure 36. If the wheel rotation is downward or away from the cutting edge as shown at (A), the wheel holds the cutter against the tooth rest. As this is the safer method, it is more commonly used. It has the objection of producing a bur on the cutting edge although this bur can easily be removed with an oilstone. There is also some danger of burning the tooth at the cutting edge unless extreme care is used. If the cutter is

ground by rotating the wheel upward or toward the cutting edge as shown at (B), there is less danger of burning the tooth and a keener cutting edge free from burs is possible. Care must be taken to hold the cutter firmly against the tooth rest, otherwise the rotation of the wheel will tend to raise the tooth off the rest. This may ruin the cutter and possibly break the wheel. In some instances, it is advisable to use this method to produce a keen cutting edge which is free from burs and chips. For example, tungsten carbide cutting tools are ground in this way.

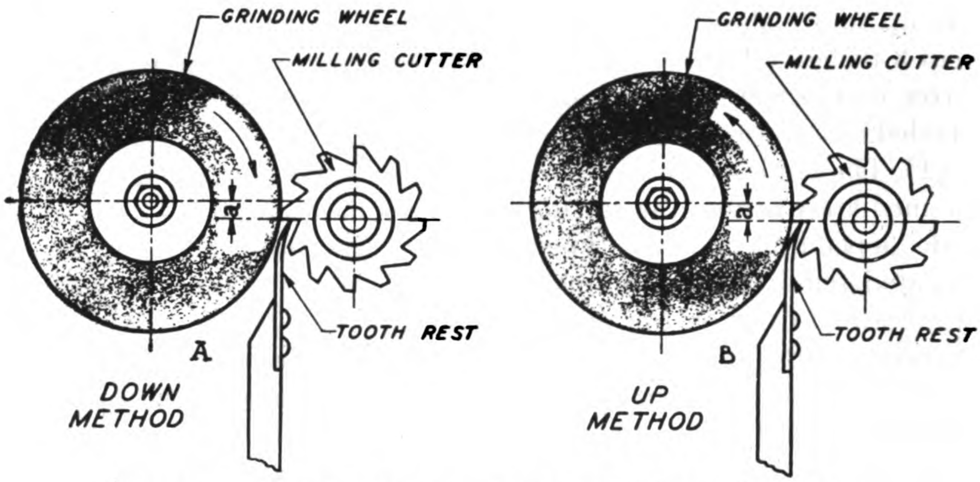


FIGURE 36.—Direction of wheel rotation for grinding milling cutters.

e. Straight or cup wheels may be used for cutter grinding although generally, if the lands on the cutter teeth are narrow, a straight wheel is used and if wide, a cup wheel is found more satisfactory. When grinding cutters, reamers, etc., a tooth rest is used to support the tooth which is being ground. The spring steel blade of this attachment is placed under the tooth. This support is set at a definite height in relation to the center of the cutter and center of the grinding wheel as shown at (A), figure 36, giving each tooth the same amount of clearance. When grinding a straight tooth cutter or reamer, the support can be at any convenient place on the machine table, head, or attachment and when grinding helical tooth cutters, it is set in a position entirely independent of the cutter movement. To calculate the tooth support height for a straight wheel, the constant 0.0088 is multiplied first by the clearance angle and then by the wheel diameter in inches.

Example: To find the elevation of the tooth rest for a cutter with a 5° clearance angle, being ground by a straight wheel 6 inches in diameter:

$$0.0088 \times 5 \times 6 = 0.264 \text{ inch}$$

NOTE.—If a cup wheel is used, the diameter of the cutter being ground and not the wheel diameter is considered in the above calculation. The setting of the tooth support for both straight and cup wheels is shown in figure 37 and tables V and VI give the tooth support specifications for various types of cutters.

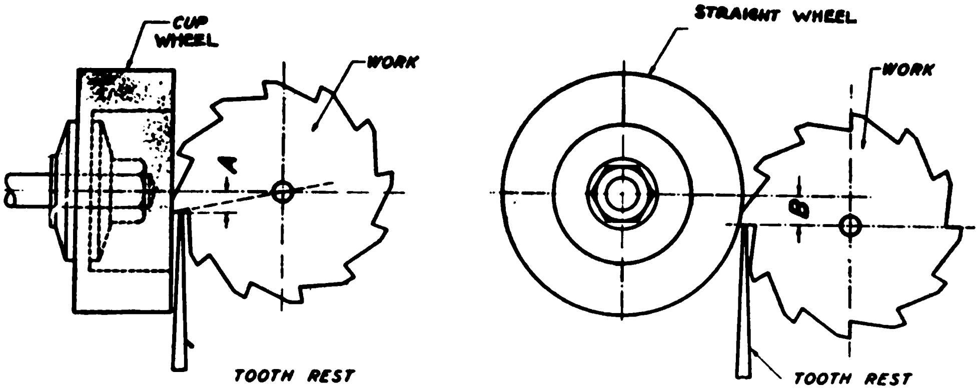


FIGURE 37.—Setting tooth rest for straight and cup wheels.

TABLE V.—*Cup wheel clearance angles*

[Tooth rest is set below work centers or at (A), figure 37, the amount indicated below]

Diameter of cutter (inches)	Clearance angle 3°	Clearance angle 4°	Clearance angle 5°	Clearance angle 6°	Clearance angle 7°
¼	0. 0066	0. 0088	0. 011	0. 013	0. 015
⅜	. 0099	. 013	. 015	. 0198	. 022
½	. 013	. 0176	. 022	. 026	. 030
⅝	. 0165	. 022	. 028	. 033	. 037
¾	. 0198	. 026	033	. 0396	. 045
⅞	. 023	. 030	. 037	. 046	. 052
1	. 0264	. 035	. 044	. 0528	. 060
1¼	. 033	. 044	. 055	. 066	. 075
1½	. 039	0528	. 066	. 079	. 090
1¾	. 04[illegible]	. 0616	. 077	. 092	. 105
2	. 0528	. 070	. 088	. 1056	. 120
2¼	. 059	. 079	. 099	. 1188	. 135
2½	. 066	. 088	. 110	. 132	. 150
2¾	. 0726	. 0968	. 121	. 145	. 165
3	. 079	. 1056	. 132	. 158	. 180
3½	. 092	. 123	. 154	. 1848	. 210
4	. 1056	. 1408	. 176	. 211	. 240
4½	. 1188	. 158	. 198	. 2378	. 270
5	. 132	. 176	. 220	. 264	. 300
5½	. 145	. 1936	. 242	. 290	. 330
6	. 158	. 211	. 284	. 3188	. 360

TABLE VI.—*Straight wheel clearance angles*

Distance (B), figure 37, is obtained by raising center of wheel above center of center and top of tooth support the amount indicated below]

Diameter of wheel (inches)	Clearance angle 3°	Clearance angle 4°	Clearance angle 5°	Clearance angle 6°	Clearance angle 7°
2	0. 0528	0. 070	0. 0937	0. 1056	0. 125
2¼	. 059	. 079	. 099	. 1188	. 141
2½	. 066	. 088	. 110	. 132	. 156
2¾	. 0726	. 0968	. 125	. 145	. 172
3	. 079	. 1056	. 132	. 158	. 187
3¼	. 0858	. 114	. 143	. 171	. 203
3½	. 092	. 123	. 154	. 1848	. 219
3¾	. 099	. 132	. 165	. 198	. 234
4	. 1056	. 1408	. 176	. 211	. 250
4¼	. 112	. 1496	. 187	. 224	. 265
4½	. 1188	. 158	. 198	. 237	. 281
4¾	. 125	. 167	. 209	. 250	. 297
5	. 132	. 176	. 220	. 264	. 312
5¼	. 1386	. 1848	. 231	. 277	. 328
5½	. 145	. 1936	. 242	. 290	. 344
5¾	. 1518	. 202	. 253	. 303	. 359
6	. 158	. 211	. 264	. 3168	. 375
6¼	. 165	. 220	. 275	. 330	. 390
6½	. 171	. 2288	. 286	. 343	. 406
6¾	. 178	. 237	. 297	. 356	. 421
7	. 184	. 246	. 308	. 396	. 437

f. The grinding of a reamer requires more care and greater accuracy than the grinding of a milling cutter. The clearance angle is ground to within a few thousandths of the cutting edge, the exact distance depending on the material for which the reamer is to be used. The narrow space parallel to the cutting edge and between it and the clearance angle is the land (fig. 38).

(1) The land of a hand reamer for use in reaming steel is 0.006 to 0.008 inches while the land of a hand or chucking reamer for cast iron or bronze should be 0.025 inch. Since a hand reamer for steel has only a narrow land, the clearance can be ground cylindrically. The work must rotate so that the heel of the blade strikes the wheel first and the slight spring in the reamer, as it contacts the wheel, gives the clearance required.

(2) Hand reamers are ground with a taper or lead at the front part of the blade to allow them to enter the hole freely without chattering. The amount of lead depends on the amount of material to be removed and is generally about $\frac{1}{16}$ inch per foot. This is done as a final operation by adjusting the swivel table of the grinder.

(3) The width of the clearance angle varies, depending on the number and depth of the flutes. The clearance angle should be as slight as possible and is ground as follows: (These instructions pertain to a straight tooth 1-inch hand reamer.)

(*a*) Aline centers.

(*b*) Place a cup wheel of the proper grade, grain, and structure on the spindle.

(*c*) Set the head approximately 10° off right angle position to prevent rear edge of wheel from striking the reamer.

(*d*) Place tooth rest in position under the tooth which is to be ground.

(*e*) Place reamer between centers and bring wheel into contact with reamer tooth.

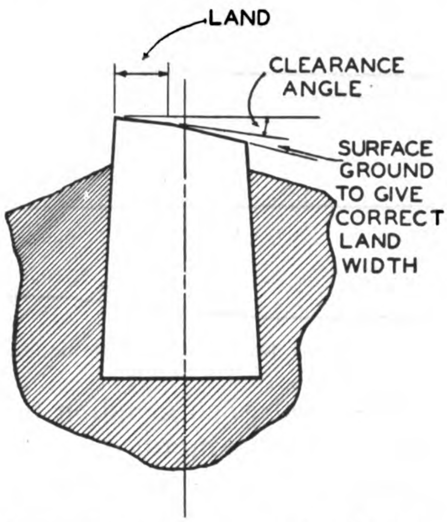


FIGURE 38.—Land and clearance angles of a reamer blade.

(*f*) Move wheel toward reamer approximately 0.0005 to 0.001 inch and grind all teeth at this setting.

(*g*) Repeat the grinding operation until lands have been ground to within 0.006 to 0.008 inch of the cutting edge.

(4) Adjustable blade reamers (shown schematically in figure 39) are ground in the following manner:

(*a*) Aline centers.

(*b*) Place a straight wheel of the proper grade, grain, and structure on spindle.

(*c*) Place work between centers and grind cylindrically, making sure that the heel of the reamer blade strikes the wheel before the cutting edge.

(*d*) Swivel the table and cylindrically grind the back slope of the blade to a taper of 3/8 inch per foot.

(*e*) Swivel the table and cylindically grind the front slope to a taper of 3/8 inch per foot, allowing about 3/8 inch for the intermediate straight part.

(*f*) Replace straight wheel with cup wheel.

(*g*) Place tooth rest in position under the first blade to be ground.

(*h*) Relieve the blade along the front, back, and intermediate parts until the land is 0.006 inch to 0.008 inch wide on all three levels.

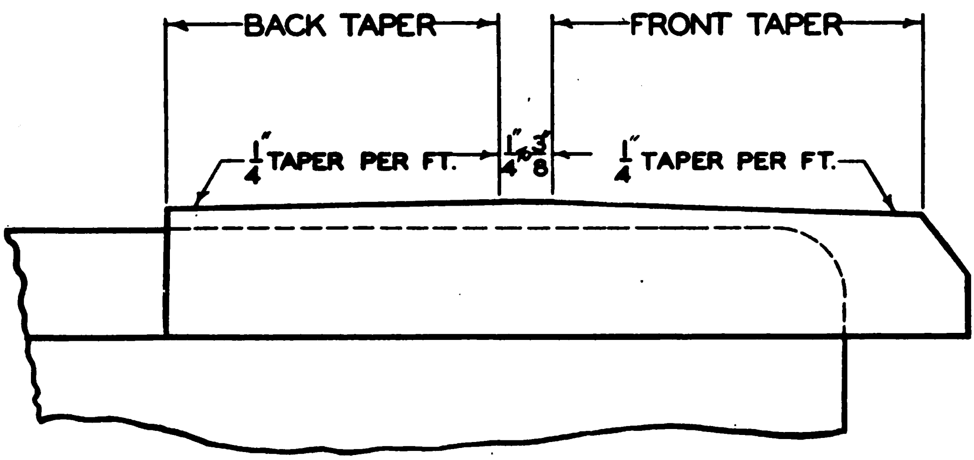


FIGURE 39.—Schematic drawing of adjustable blade reamer.

(5) Great care must be used when grinding taper reamers, as both the taper and diameter must be maintained absolutely correctly. The method of grinding clearance on the tooth face of tapered reamers is shown in figures 40 and 41. The general procedure is as follows:

(*a*) Aline centers.

(*b*) Place a straight wheel of proper grade, grain, and structure on spindle.

(*c*) Set swivel table on proper angle and grind cylindrically to the correct diameter plus 0.001 inch.

(*d*) Check taper with gage for accuracy.

(*e*) Change wheel if necessary and clamp tooth rest on wheel head under blade being ground.

(*f*) Grind clearance on each tooth, leaving one tooth 0.0005 inch higher than the other teeth to give a clean cutting action with freedom from chatter.

(*g*) Oilstone the cutting edges or grind lightly with a cup wheel.

(*h*) After the reamer is ground and before using, a test hole should be reamed and checked with a taper plug gage.

(6) The method of grinding the teeth of a reamer or cutter so that the periphery of each cutting edge is equal is shown in figures 42 and 43. The general procedure is as follows:

(*a*) Aline centers.

(*b*) Place a straight wheel of the proper grade, grain, and structure on spindle.

(*c*) Set up work in machine and adjust tooth support.

(*d*) Bring cutting edge of cutter (supported on tooth rest) into contact with wheel and take a cut of approximately 0.001 inch.

(*e*) Grind each tooth at this setting by indexing the work.

(*f*) After all teeth have been ground, move cutter into wheel 0.0005 to 0.0015 inch and repeat above operations.

g. When grinding a comparatively heavy cutter on the cutter bar of the universal head, the end of the cutter bar can be supported by the footstock. The wheel spindle column is swiveled very slightly to prevent the back edge of the wheel from striking the cutter. Either a straight or cup wheel can be used and the cutter is mounted on an arbor held in the universal head. The tooth rest is attached to the head of the machine as shown in figure 44.

h. Saws up to 16 inches in diameter may be ground on the universal head. The saw is mounted on a sliding shell attached to the cutter bar and is moved across the face of the wheel by sliding it along the bar. As the tooth rest is mounted on the head of the machine the clearance is adjusted by raising or lowering the wheel. A typical set-up for grinding saw teeth is shown in figure 45. When grinding the side of a saw, the saw is held on the face chuck (fig. 46) and the table is swiveled slightly to obtain the desired clearance. The necessary concavity is produced by the intersection of the vertical plane of the saw with the face of the wheel.

i. Either solid or inserted tooth, side or face milling cutters may be ground on the universal head when mounted on an arbor in the tool rest. The universal head is set at a slight angle to make the cutter teeth taper toward the center of the cutter to prevent dragging. When using a cup wheel, the tool rest of the universal head is swiveled for the required angle. If a straight wheel is used, the tool rest and cutter arbor should be set in a horizontal position and the wheel raised or lowered to obtain the correct clearance. The tooth rest may be placed either on the work table or on the back rest of the universal head. A typical set-up for grinding side milling cutter teeth is shown in figure 47.

(1) When grinding the side teeth of an angular cutter, the cutter is mounted on an arbor in the taper shank mill sleeve. Either a

straight or cupped wheel may be used for this purpose. The angular teeth are ground by turning the cutter around on the arbor and swiveling the universal head to the face of the cutter. A typical set-up for this operation is shown in figure 48.

(2) When grinding the end teeth of a coarse tooth end mill, the cutter is again held in a taper sleeve. The work head is swiveled vertically to obtain the required angle of clearance and the universal head is offset slightly to grind the teeth 0.001 inch to 0.002 inch low in the center to prevent dragging. A set-up for this operation is shown in figure 49.

j. In grinding form cutters, the face of the teeth must be kept radially true and of equal height. This is accomplished by radial grinding. A correctly ground cutter tooth is shown at (A) and (D), figure 50. The tooth shown at (B) would drag and make a shallow cut, whereas the tooth shown at (C) would gouge and make an excessively deep cut. While grinding, care should be exercised to keep the tooth face square with the sides of the cutter. The right and wrong methods of grinding form cutters are shown in figure 51.

(1) When grinding a cutter for the first time, the backs of the teeth should be ground before the cutting edges are sharpened. This extra operation is necessary to provide proper location of the actuating pawl as it is set to the back of the teeth, and if they are ground uniformly, more accurate results are obtained. This operation is shown in figure 52 while the type of cutter sharpening attachment usually used is shown in figure 53.

(2) Concave form cutters are ground on the radial grinding attachment as shown in figure 54. When grinding this type of cutter, a diamond point is clamped to the attachment as shown in figure 7, and the wheel is trued to the desired radius. If the cutter has fine teeth, a small-diameter wheel must be used to prevent the wheel from striking teeth on either side of the one being ground. The cutter is placed between the work holders and the tooth rest set at the same height as the work centers. The wheel is raised or lowered to obtain the proper clearance angle and the wheel spindle is swiveled to the angle of the surface to be ground. Before starting the grinding operation, the work should be fed past the wheel to determine whether the cutter tooth remains equidistant from the wheel in all positions. If it swings out on either side, it should be adjusted across the slide with the thumbscrews as shown at (8), figure 7. The work may then be fed into the grinding wheel by the adjusting nuts as shown at (7), figure 7.

(3) A simple method of indexing a form cutter by means of a second cutter on the same arbor is shown in figure 55. This arrangement assures positive radial accuracy although care must be taken to see that the second cutter is held firmly against the stop.

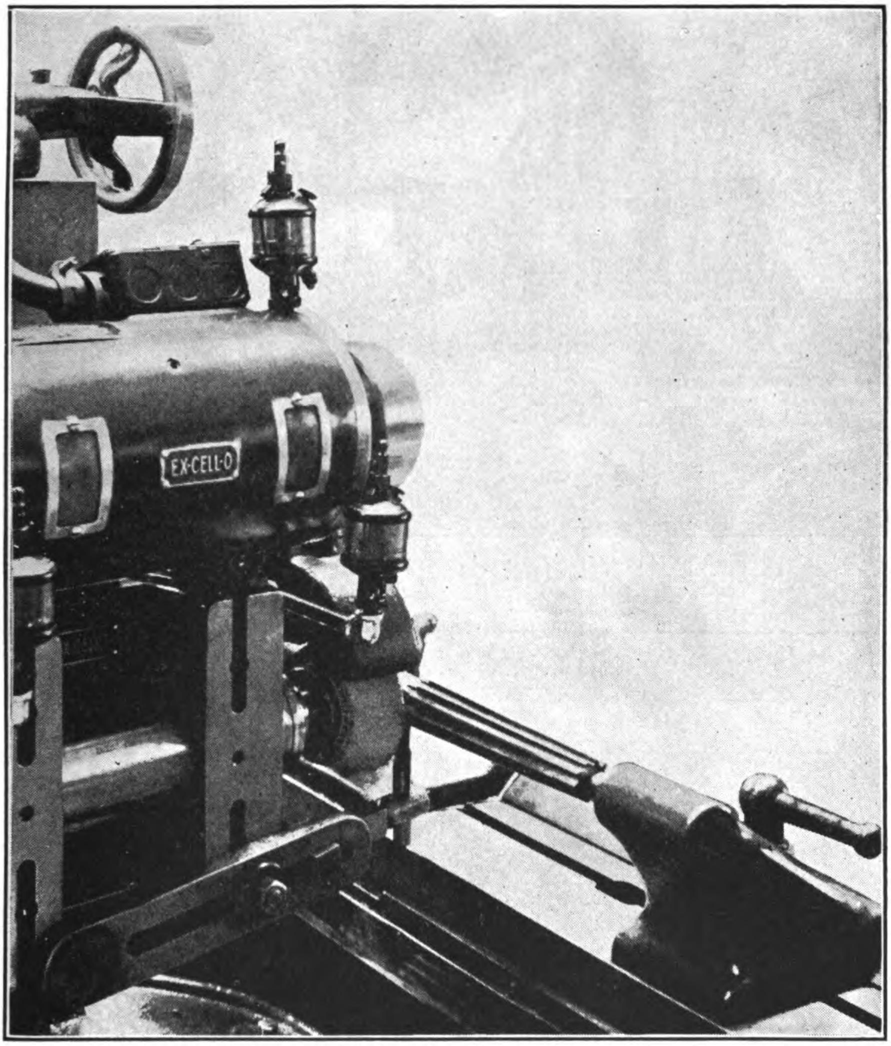


FIGURE 40.—Grinding clearance on tapered reamer.

k. Hobs are ground between centers, using a dish wheel as shown in figure 56. The concave side of the wheel is used for helical cutters while the straight side is used for straight-fluted hobs. The attachment is geared to a rack parallel with the table and a gear drive is provided to obtain rotary movement of the hob for helical grinding. Indexing is accomplished by means of an index plate attached to the headstock spindle.

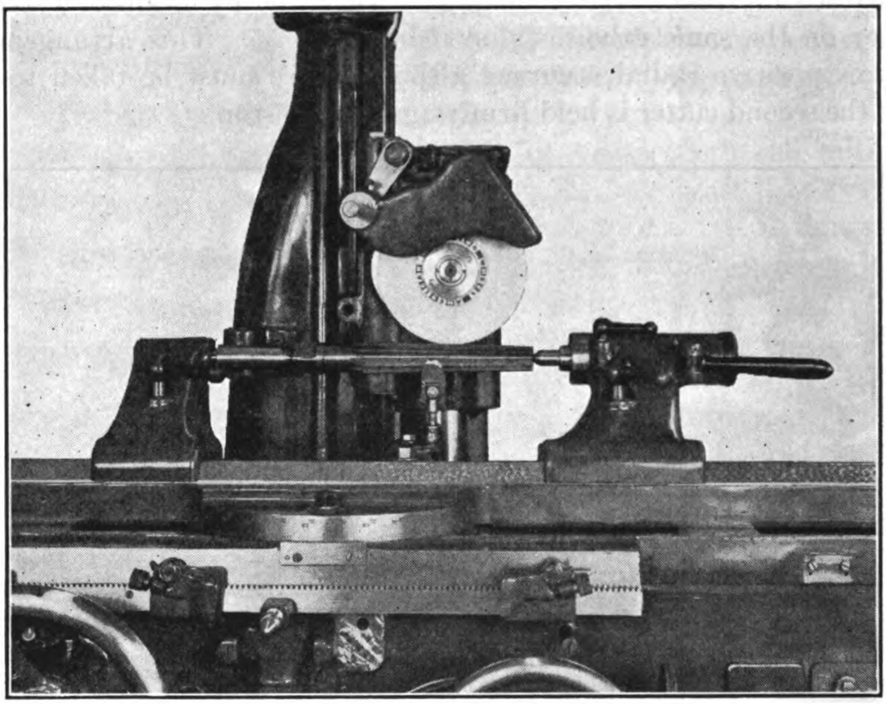


FIGURE 41.—Grinding face of teeth of tapered reamer.

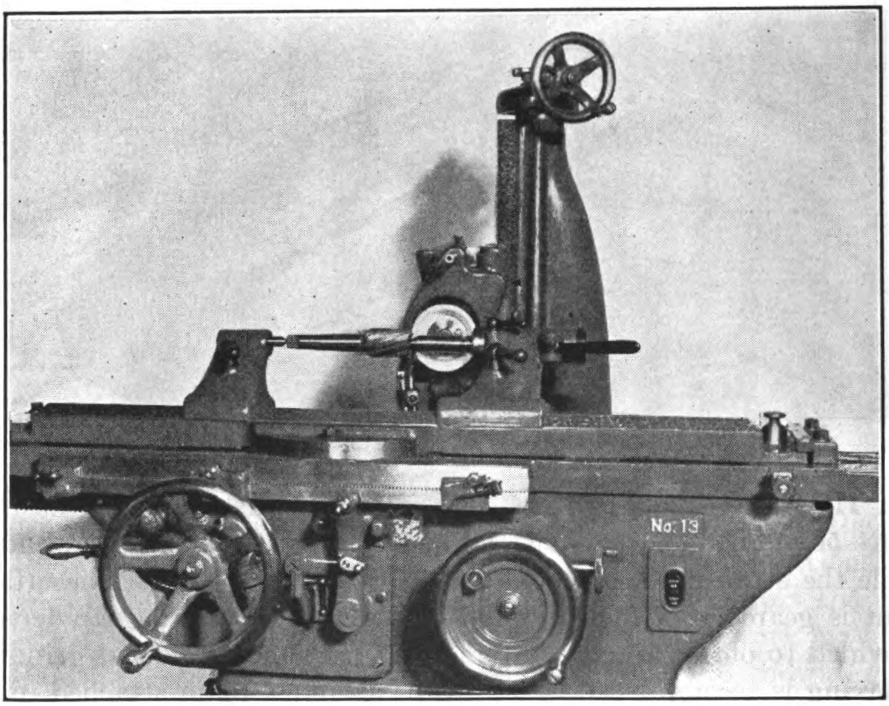


FIGURE 42.—Grinding clearance angle on end mill.

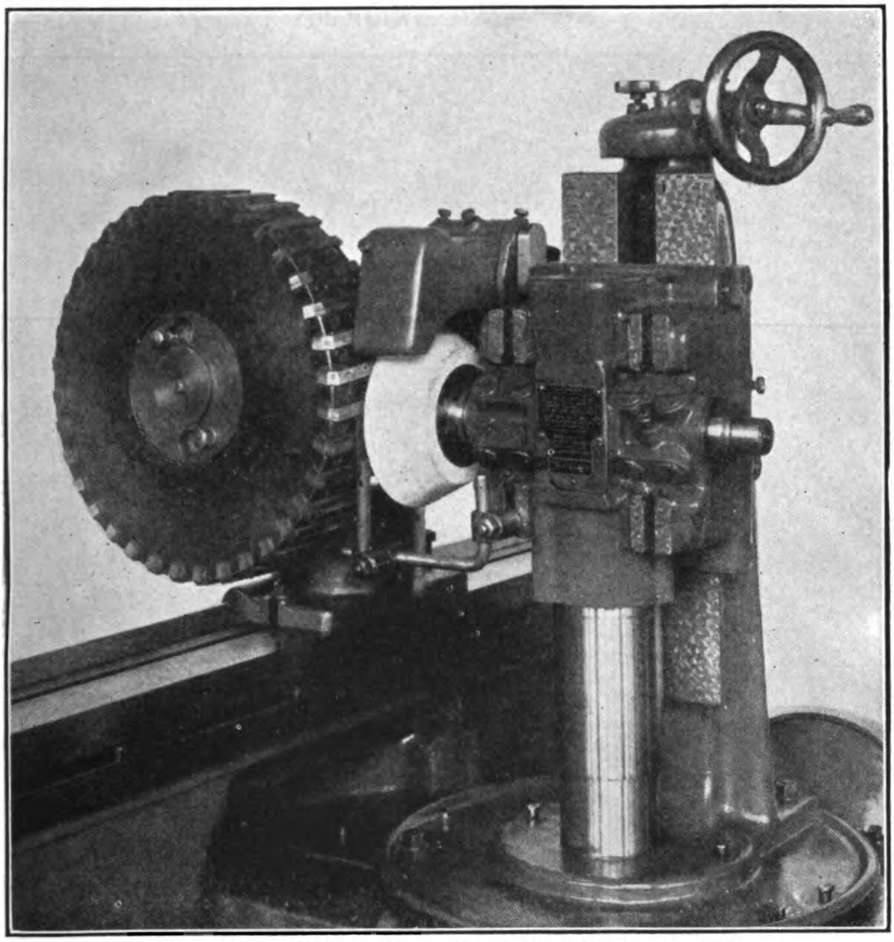


FIGURE 43.—Grinding clearance angle on large face mill.

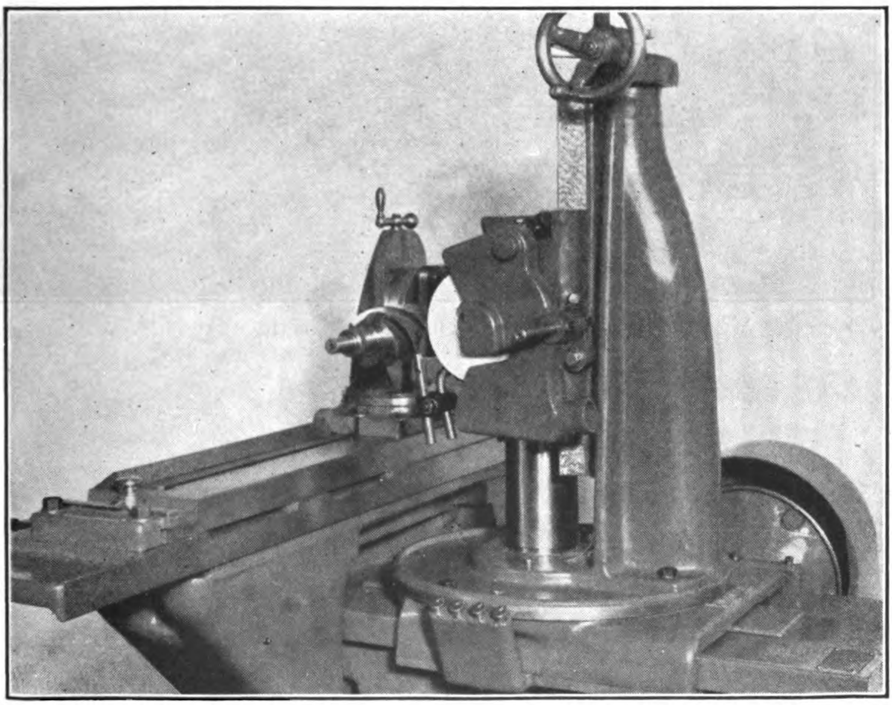


FIGURE 44.—Grinding clearance angle on spiral tooth milling cutter.

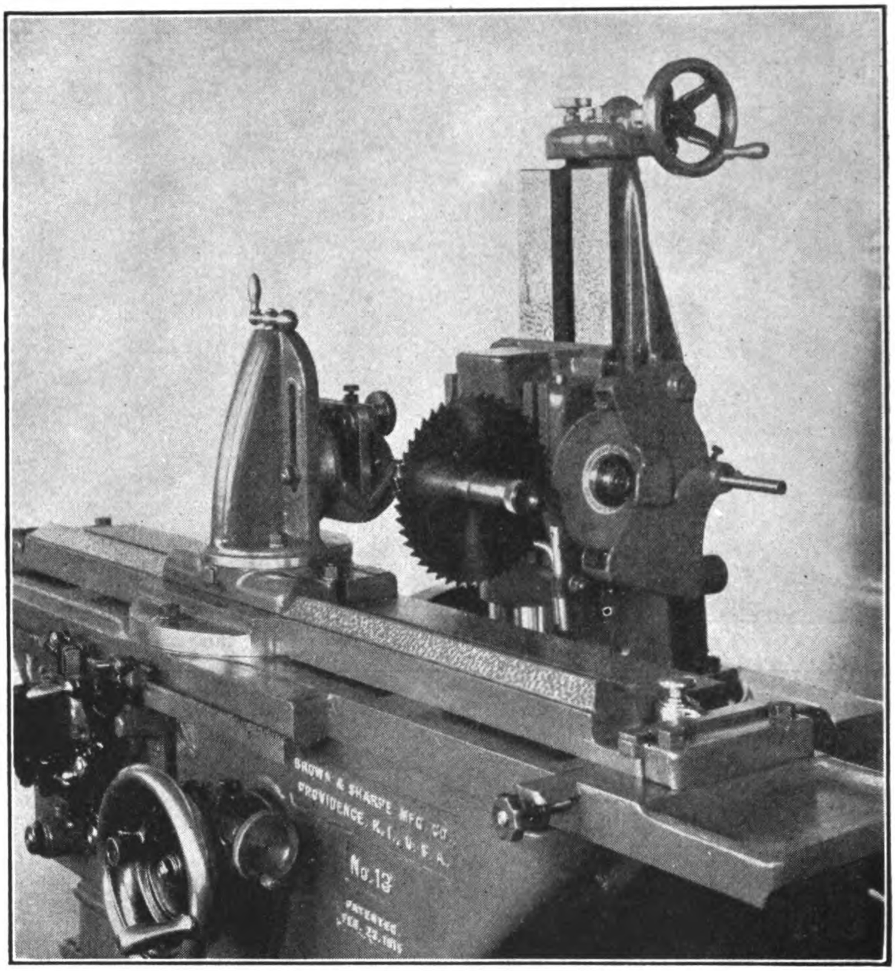


FIGURE 45.—Grinding saw teeth.

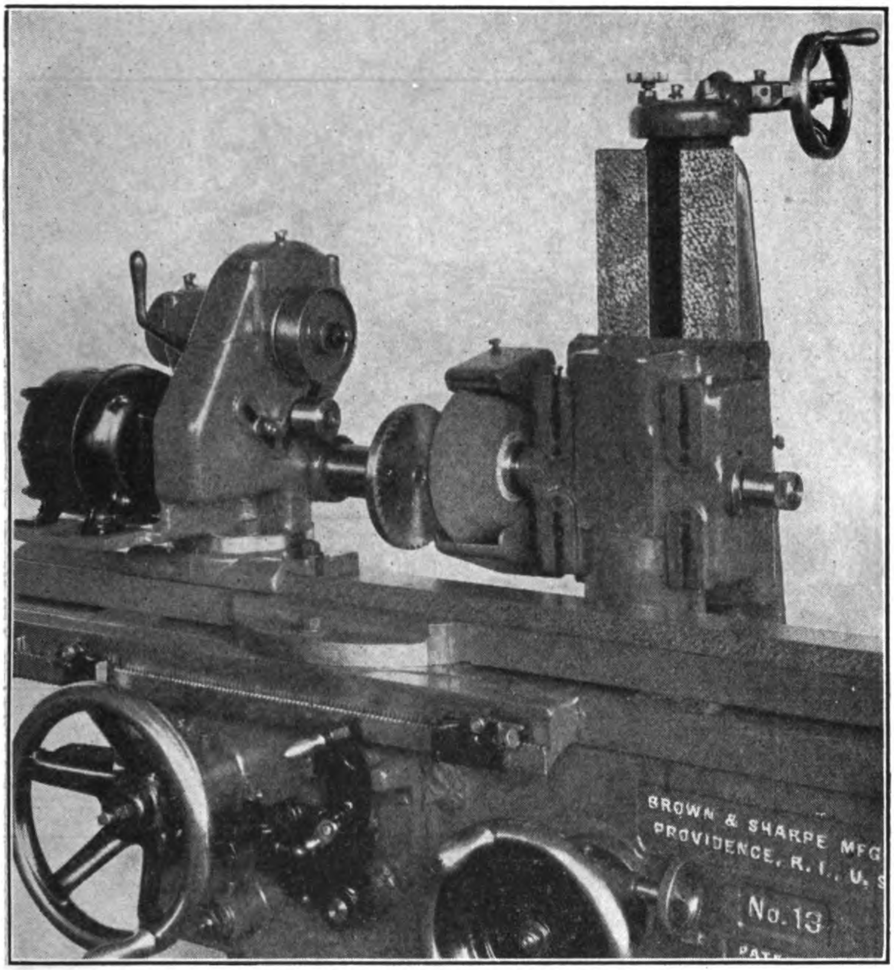


FIGURE 46.—Grinding the side of a saw.

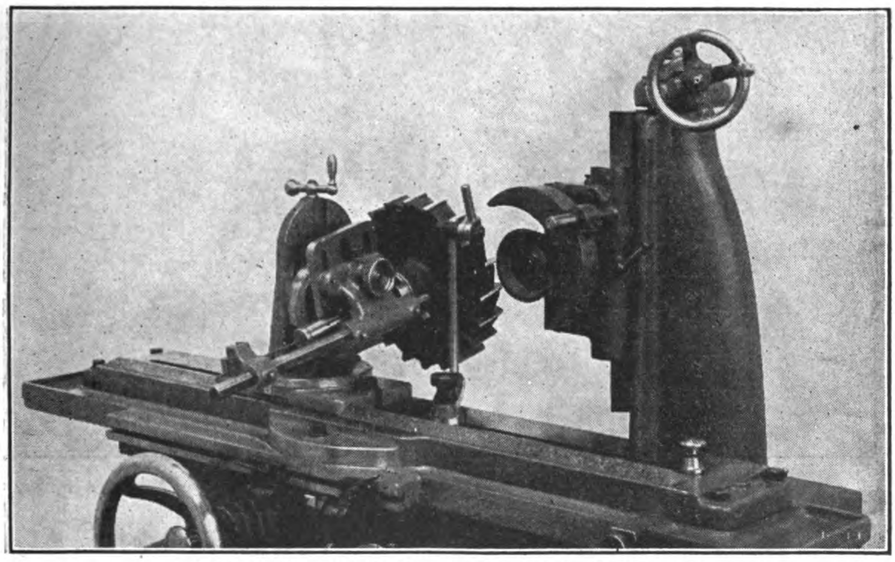


FIGURE 47.—Grinding side milling cutter teeth.

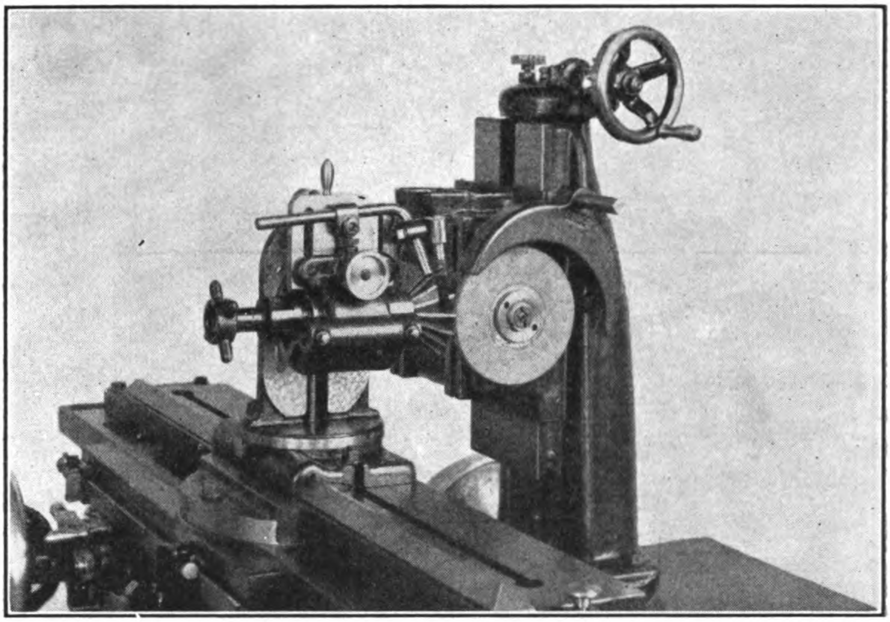


FIGURE 48.—Grinding side teeth of an angular cutter.

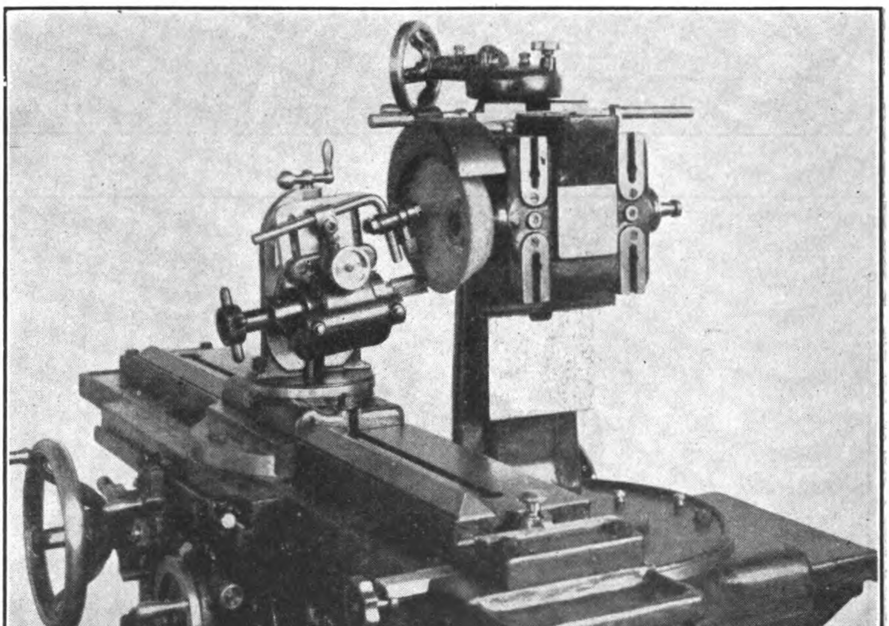
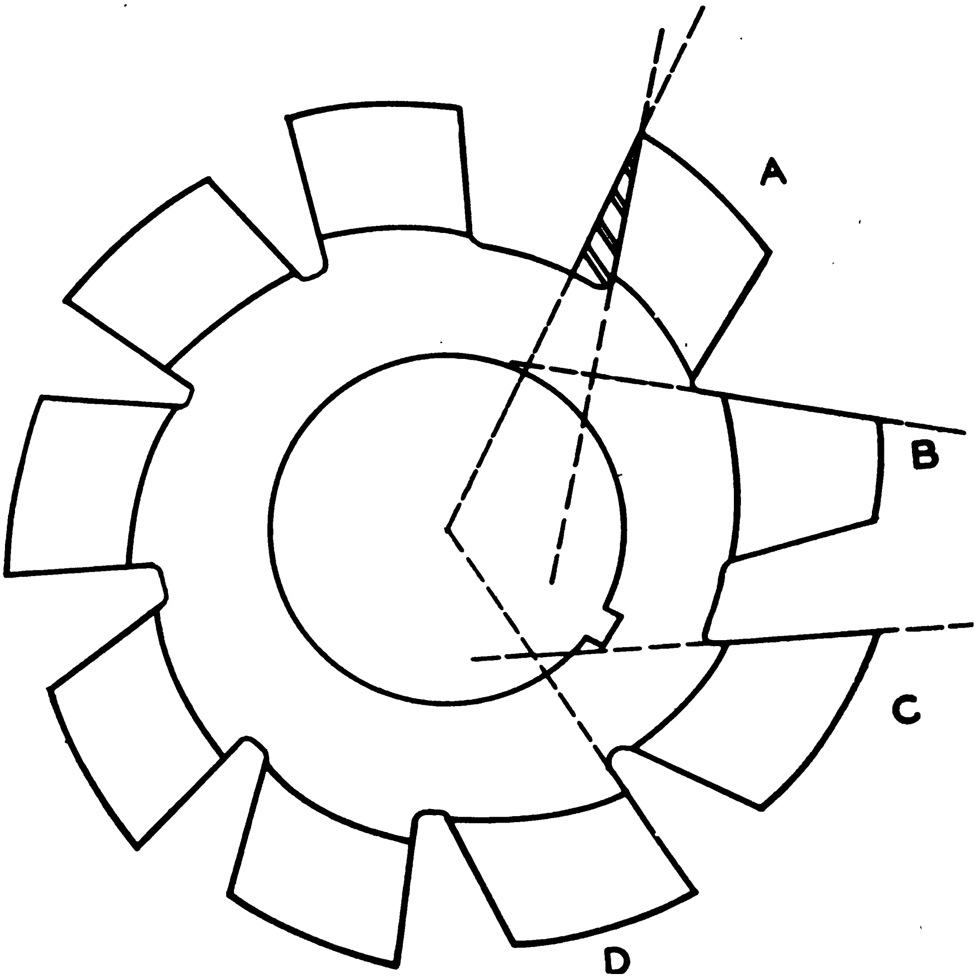
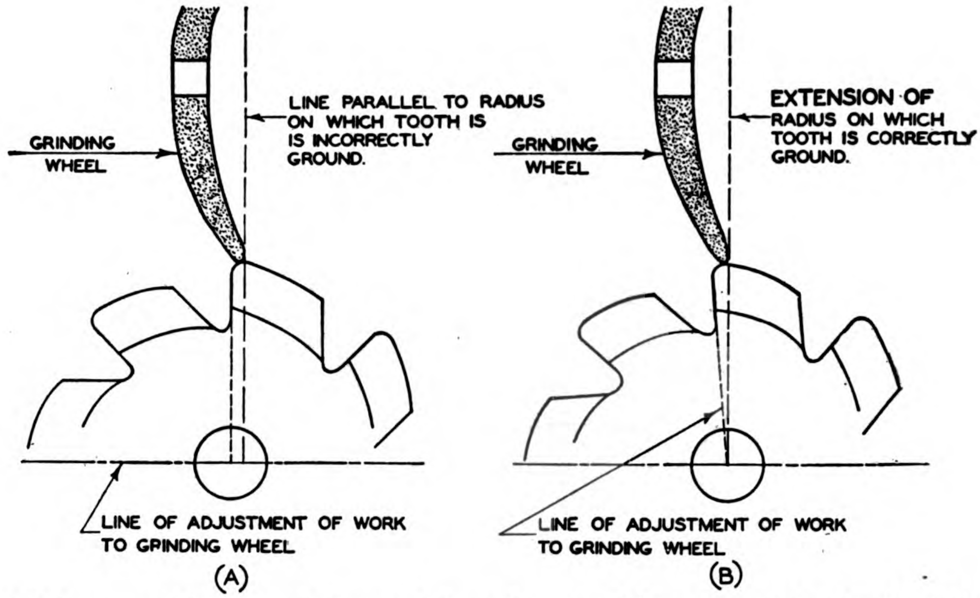


FIGURE 49.—Grinding end teeth of a coarse tooth end mill.



A. Correctly ground (with rake).
B. Incorrectly ground (excessive positive rake).
C. Incorrectly ground (excessive negative rake).
D. Correctly ground (without rake).

FIGURE 50.—Correct and incorrect grinding of form cutter teeth.



A. Wrong way (face of tooth is ground in a plane parallel to radius deforming the tooth profile).
B. Correct way (face of tooth is ground in a radial plane retaining original tooth profile).

FIGURE 51.—Grinding radial tool gear cutter.

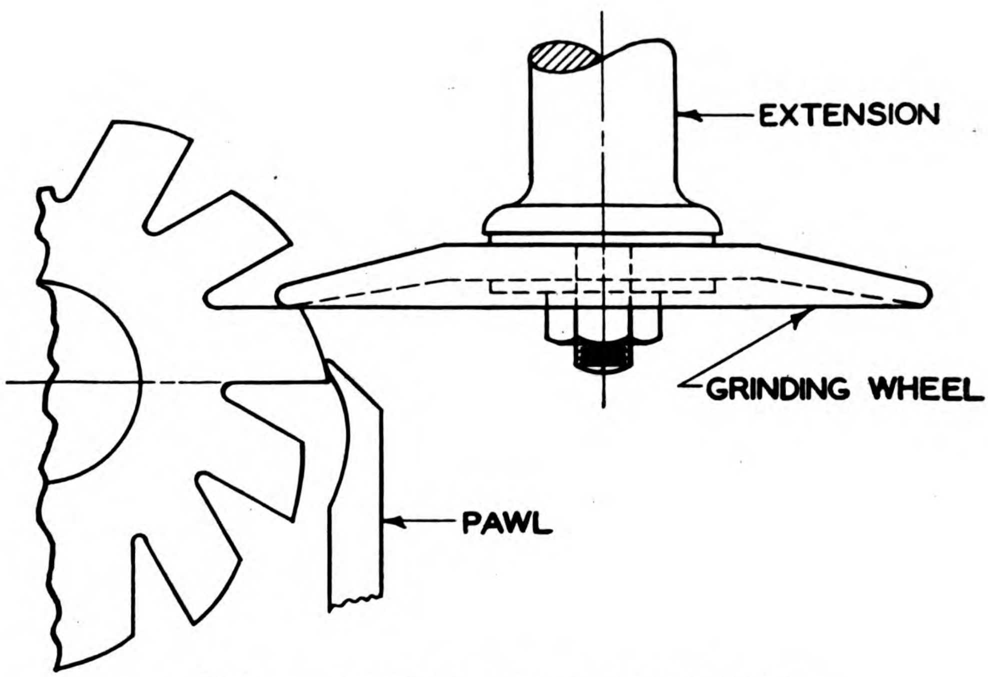


FIGURE 52.—Grinding tooth backs on new form cutter.

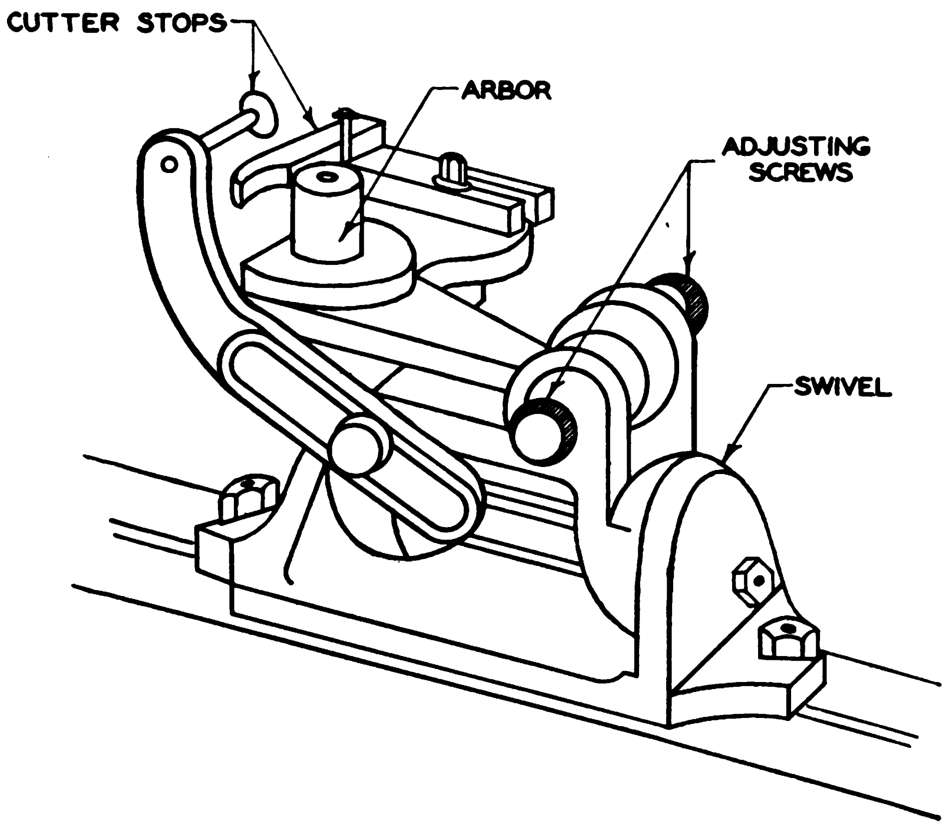


FIGURE 53.—Cutter sharpening attachment.

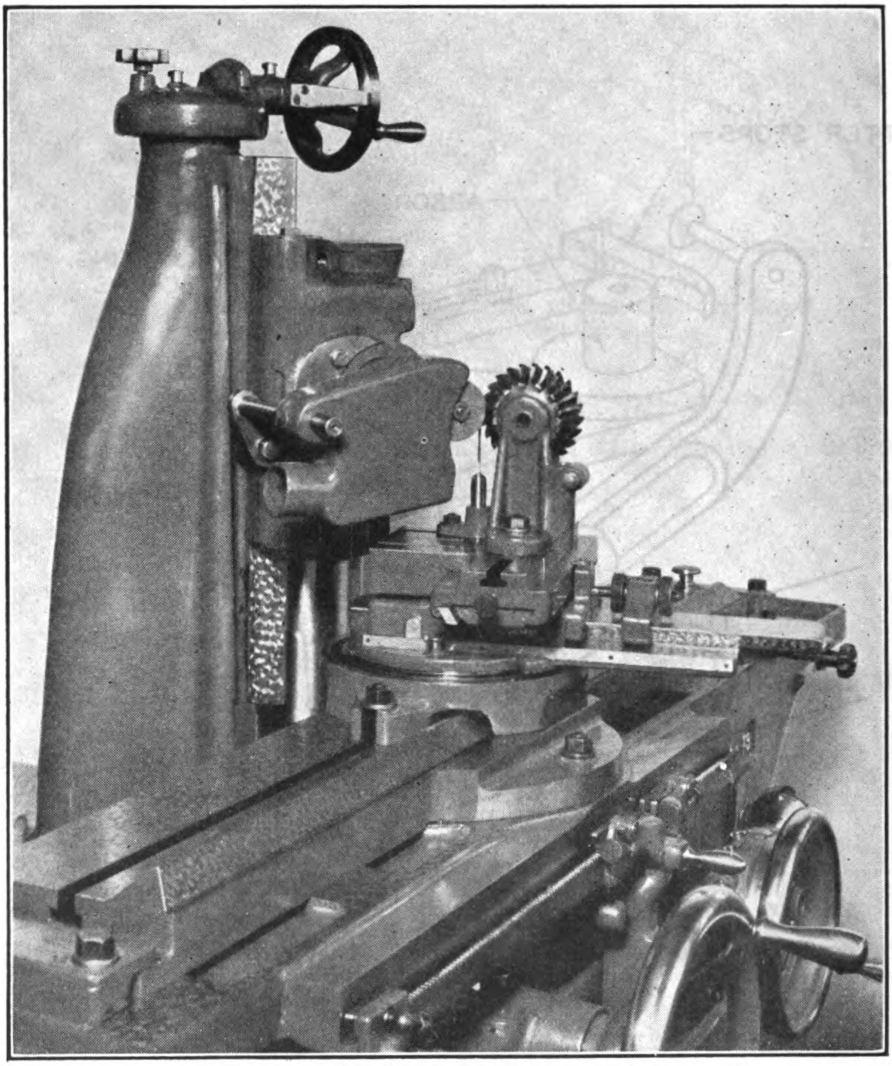


FIGURE 54.—Grinding a concave cutter.

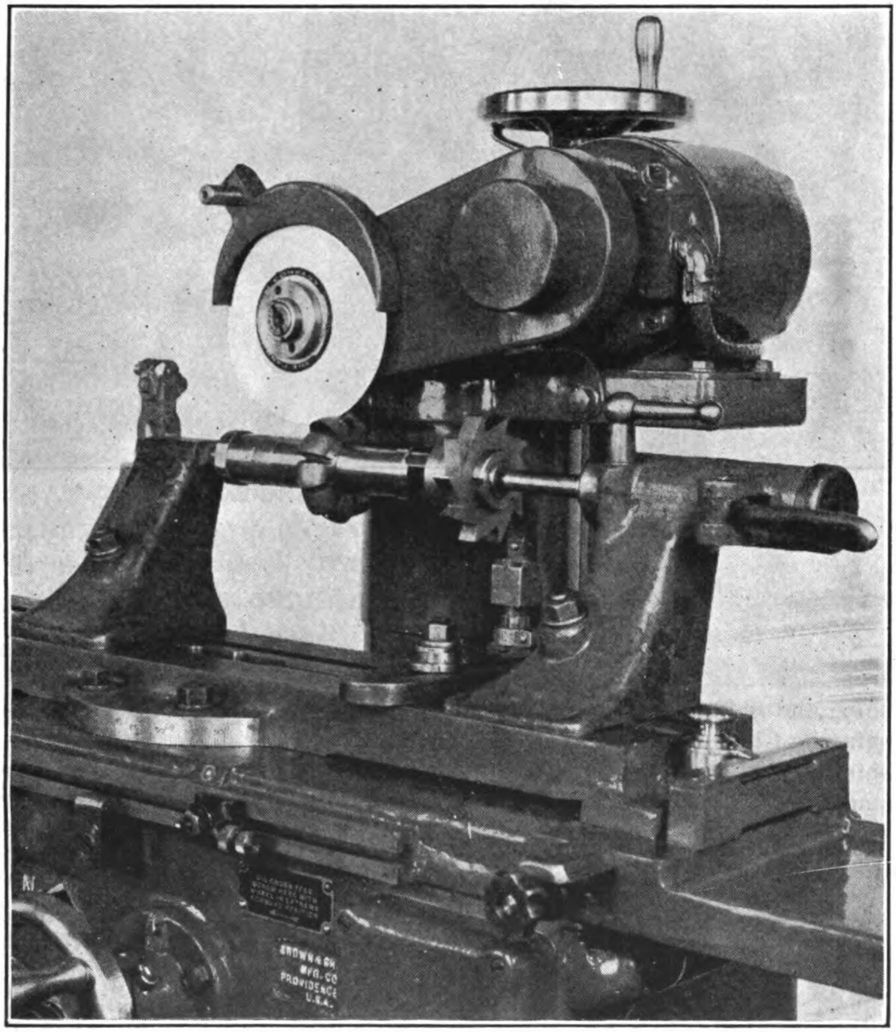


FIGURE 55.—Use of an extra cutter for indexing.

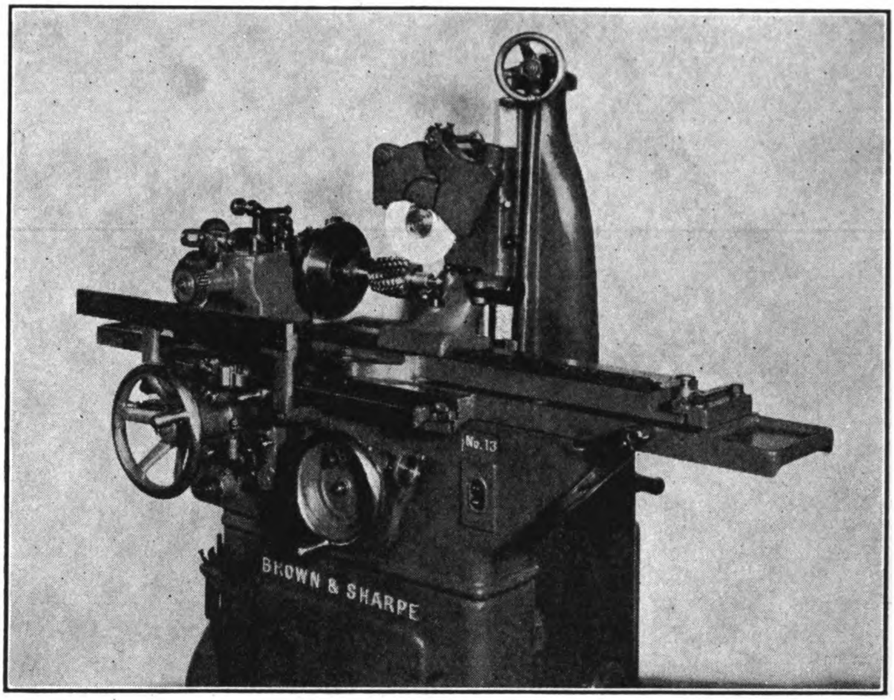


FIGURE 56.—Grinding a helical grooved hob.

SECTION IV

FINISHING

22. General.—Polishing is the process of producing a smooth, glossy finish on the surface of an object. This is usually accomplished by removing a small amount of material from the part by means of various types of cushion wheels or flexible belts impregnated or coated with an abrasive compound and driven at a relatively high speed. The wheels used for polishing are commonly known as "set-up" wheels. Polishing may have for its objective the reduction or smoothing of the surface to a common level for high finish where accuracy of dimension is not important, or it may be employed for removing relatively large amounts of material from parts of irregular contour. Polishing may be subdivided into the following types:

a. Roughing.—This consists of polishing on a dry wheel with coarse abrasive (up to No. 60 grit).

b. Dry finishing.—This process is similar to roughing but the abrasives are finer. No. 70 to 120 grit is used.

c. Oiling.—This is accomplished with grit No. 120 or finer. In this process, the abrasive material used on the wheel is greased with tallow or a similar substance.

d. Buffing.—This is a smoothing operation which is accomplished more by plastic flow than by abrading. The abrasives employed are finer and usually softer than those used in polishing and instead of being firmly cemented to the wheel are merely held by "grease cake" or other similar substances. The object of buffing is to produce a high luster or color without any particular regard for accuracy of dimension or plane. Buffing may be subdivided into the following:

(1) *Cut-down buffing.*—This process produces a rapid smoothing action with fast-cutting compounds (usually containing tripoli or silica) and relatively hard buffs. It is accomplished with high pressures and peripheral speeds, allowing both abrasion and plastic flow to occur.

(2) *Color buffing or coloring.*—This is a secondary process of buffing which imparts a very high luster or surface finish to buffed work. Soft abrasives such as crocus (iron oxide) or lime are used.

23. Polishing and buffing wheels.—*a.* The wheels that are most commonly used for polishing operations are as follows:

(1) *Sewed canvas wheel.*—This is a type of wheel generally used for severe polishing operations with abrasive grain sizes from 24 to 46.

(2) *Disk canvas wheel.*—This wheel is often used for heavy work and consists of several canvas disks bonded together with a suitable glue. Where a hard face is required, the bond is extended near the periphery on both sides of the disk.

(3) *Compress wheel.*—This is a very good wheel to be used when it is necessary to form a polishing face to suit an irregular shape on the work. It is also used extensively in polishing small parts where it is necessary to hold the corners and edges of the article to specification. A compress wheel is generally made of canvas or leather and may be had in hard, medium, or soft grades.

(4) *Felt wheel.*—This type of wheel is generally used for finishing with an abrasive grain size of 150 or finer. It is used where a high luster is desired on steel, iron, brass, or aluminum castings.

(5) *Sewed buff polishing wheel.*—This wheel is used for both roughing and finishing. It is soft and flexible and very efficient for polishing brass, aluminum, and steel sheet.

(6) *Sheepskin leather wheel.*—This is a very soft, flexible finishing wheel used extensively for brass, aluminum, and stainless steel sheet.

(7) *Walrus leather wheel.*—This wheel is used for finishing jewelry, small arms, and other fine work.

(8) *Steel wire wheel.*—This wheel is used extensively for the rough polishing of castings, hot-rolled steel, etc.

b. Wheels used for buffing are of softer material than those used for polishing. They are usually referred to as "buffs" and are made of bleached sheeting, flannel, etc. The material is cut in various diameters and sewed into sections which are put together to make up the buff. The sections are often slotted and perforated for ventilation.

24. Polishing and buffing speeds.—The proper speed for polishing and buffing is governed by the type of wheel, nature of work, and finish desired. For polishing and buffing operations in general, where the wheels are in perfect balance and correctly mounted, a speed of approximately 7,500 r. p. m. is safe and gives satisfactory results for most work.

25. Polishing and buffing abrasives.—*a.* The abrasive grains used for polishing must vary in characteristics for the different operations to which they are applied and are graded from coarse to fine in even numbers ranging from 4 to 240.

b. Buffing abrasives are comparatively fine and are often made up in the form of paste, sticks, or cakes; the abrasive being bonded together by means of grease or other similar material. The abrasive sizes for buffing are 280, 320, 400, 500, and 600. Some manufacturers use letters and numbers to designate grain size, such as F, 2F, 3F, 4F, XF.

c. The glue that holds the abrasive to the wheel must be strong and flexible in order to firmly hold it to the wheel face. Various glues may be purchased under different trade names and directions for mixing are usually furnished with each product. The following general points apply to the handling and mixing of all glues and should be emphasized:

(1) Glue should be stored in a cool, dry place.

(2) Glue and water should be measured by weight rather than by volume.

(3) Cold, distilled, or otherwise pure water should be used for soaking.

(4) The glue should be completely covered with water while soaking.

(5) Ground glue should be soaked 3 hours, flake glue 6 hours, and cake glue 12 hours.

(6) Glue pots should be kept covered and any scum removed that accumulates.

(7) The glue should be stirred while melting.

(8) The temperature should never be allowed to rise higher than 140° F.

(9) Mixed glue should never be allowed to stand overnight before using.

(10) Coarse grains require thick glue while fine grains require thin glue. Glue may be thinned accordingly by diluting it with water to suit the grain.

(11) Wheels and abrasives should be at approximately 120° F. when the glue is applied.

(12) After the wheels are glued, they should set approximately 48 hours before being used.

d. It is often necessary to use more than one polishing wheel for certain kinds of work. For example, one wheel may be charged with coarse abrasive to remove scale or rust caused from heat-treating quickly, a second wheel may be charged with fine abrasive to remove the marks left by the first, and a third may be charged with flour abrasive for the final finish. Tools, such as wrenches, screw drivers, etc., are polished by this method. Only parts of some tools are polished, such as the knurled handles of gages and the grooves of reamers and milling cutters, etc.

26. Lapping.—*a.* Laps are usually made of soft cast iron, copper, brass, or lead although the best type for general purposes is soft, close-grained cast iron. Regardless of metal used, the lap must be softer than the material to be lapped and may be of any desired shape and side. For best results, the lapping surface must be true. A flat lap for roughing cuts better when grooved. These grooves are usually located about ½ inch apart and extend in both directions across the face of the lap forming a series of squares. A flat lap of this type is shown in figure 57. Internal laps are of lead, cast around a steel arbor, and some means are provided to expand the lap slightly to take up its wear. The more elaborate internal laps are made of cast iron or copper in the form of a split shell mounted on a suitable steel mandrel. The shell is prevented from turning by a small dowel pin. Several forms of internal laps are shown in figure 58. External laps are usually made in the form of a double ring. The outer ring is made of steel and holds an inner ring of cast iron, copper, brass, or lead. An external lap is shown in figure 59.

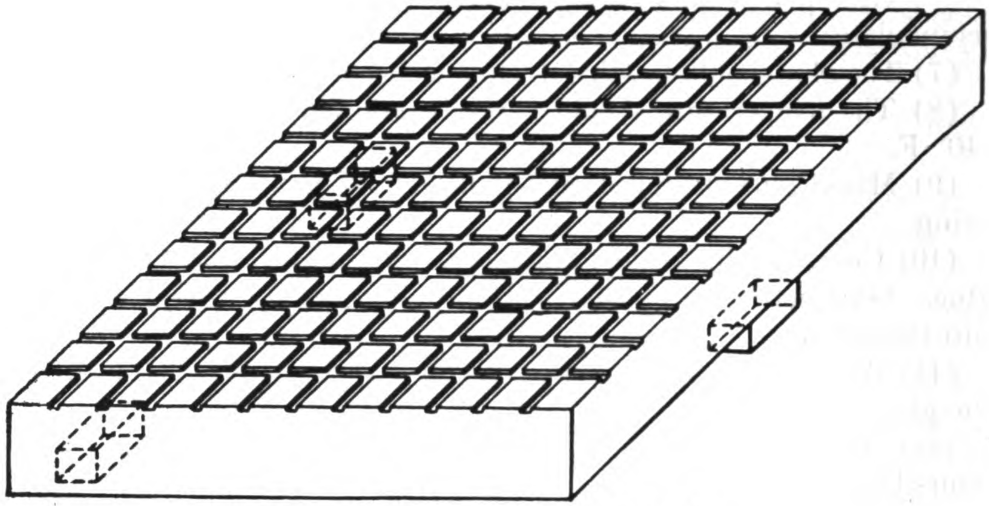


FIGURE 57.—Lapping plate for flat work.

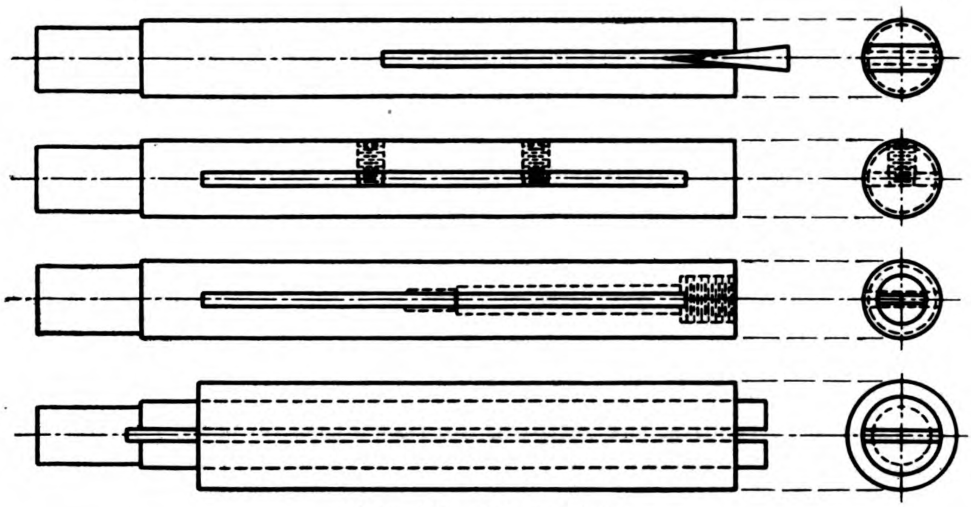


FIGURE 58.—Internal laps.

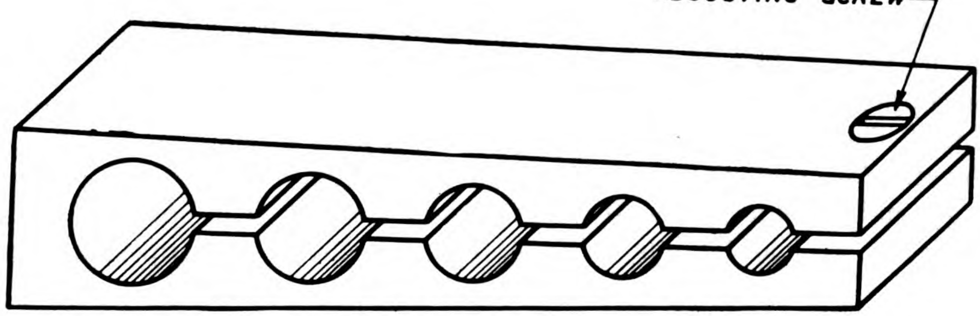


FIGURE 59.—Multiple external lap.

b. Only the finest abrasives are used for lapping and may be either natural or artificial. A coarser abrasive is used for roughing than for precision work. A high grade lapping compound may be prepared by sifting flour emery through a cloth bag to obtain only the very fine particles. The sifted emery is then placed in lard or sperm oil and allowed to stand for 1 hour, during which time the larger particles will settle to the bottom. The oil is then carefully poured off to prevent disturbing the sediment at the bottom. If it is desired to obtain a finer abrasive, this mixture is allowed to stand for several hours, after which time the oil is again poured off. This process may be continued until a grade is obtained that is suitable for the work to be done.

c. To charge a flat cast-iron lap, a very thin coating of prepared abrasive is spread over the surface and the small particles pressed into the lap with a hard steel block. There should be as little rubbing as possible and when the surface is apparently charged, it should be cleaned and examined for bright spots. If the surface has a uniform gray appearance, it is fully charged but if bright spots are visible, the charging operation should be repeated. The surface should not be allowed to become dry while lapping. To charge cylindrical laps for internal work, a thin coating of prepared abrasive is spread over the surface of a hard steel block. The lap is then rolled and pressed over this steel block to imbed the abrasive into its surface. The inner surface of external laps may be charged by rolling the abrasive in with a hard steel roller that is somewhat smaller than the lap.

d. The selection of lubricants for lapping depends upon the kind of abrasive used and the material of which the lap is made. For general purposes, lard oil gives the best cutting action. Gasoline and kerosene are very good on cast-iron laps while turpentine and alcohol are adaptable when using a natural abrasive such as carborundum or emery or copper laps. Soda water may be used only when other lubricants are not available as the results from its use are only fair.

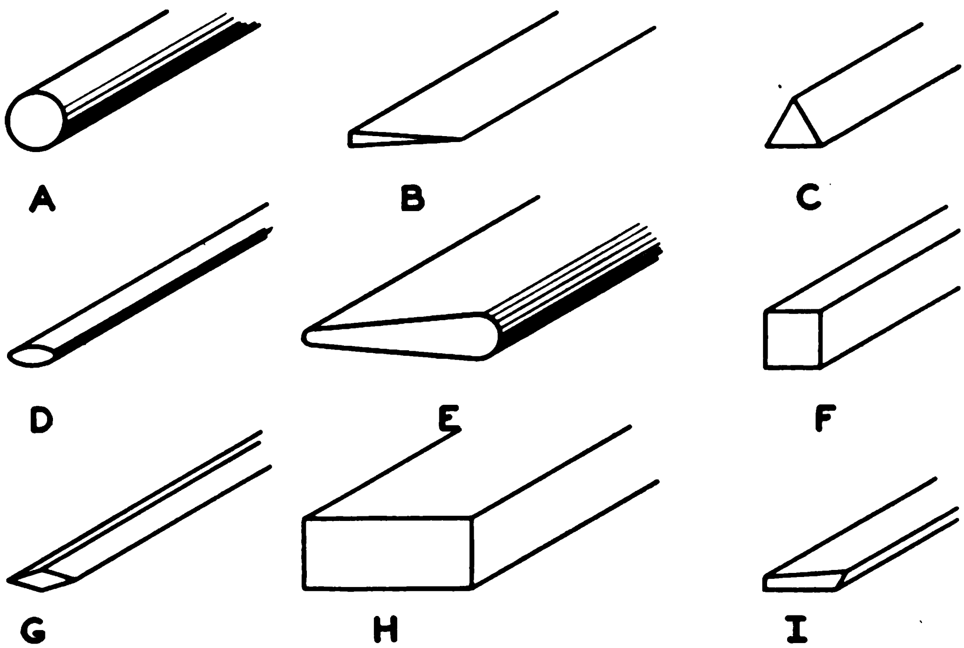
27. Oilstones.—*a.* On cutting tools, the grinding operation often leaves a series of small points which terminate in a slight bur or wire edge. When the tool is used, this bur will leave toolmarks which are difficult to remove and the edge is soon broken off leaving the tool dull. By the proper use of oilstones immediately following grinding the burs may be eliminated. The oilstoned tool has a keener cutting edge and leaves a finish with few, if any, marks. Oilstoning produces a firmer edge which will not break down readily.

b. Reamers, milling cutters, and boring tools, especially when used for finishing operations, are improved by oilstoning. All three rotate

when in operation and therefore it is important that the original angle of clearance be maintained. To accomplish this, the oilstone should always be used on the inside of the cutting edge. Care should be taken in selecting the proper shape of oilstone so that the cutting edge may be restored without disturbing the clearance or changing the outside diameter of the reamer.

c. Oilstones are also used for reaming and honing operations when mounted in a suitable holder. This holder is generally motor-driven and provision is made for spring tension to be applied to the stones.

d. The natural stones generally used are Arkansas and Washita, varying from a fine crystallized structure to the porous whetstone grit. The sharpness of the grit of a Washita stone depends upon the character of its crystallization. The Arkansas stones are of finer grain and resemble marble in appearance. They are used for sharpening delicate instruments and for tools where a keen, smooth edge is required. The Turkey and Hindustan stones are also natural abrasives, but are not as widely used as the first two mentioned. Many artificial oilstones are available for various classes of work. They are furnished in fine, medium, and coarse grit and in various shapes and sizes as shown in figure 60.



A. Round (type 10).
B. Knife edge (type 28).
C. Triangular (type 7).
D. Oval (type 50).
E. Radius (type 14).
F. Square (type 4).
G. Chisel point (type 26).
H. Rectangular (type 24).
I. Bevel edge (type 23).

FIGURE 60.—Oilstones.

e. Coarse stones are used for sharpening large, very dull or nicked tools, machine knives, etc. Medium stones are used for sharpening carpenter's tools as well as tools used for cutting cloth, leather, rubber, and paper. The fine grit stones are generally used for special tools requiring a fine, keen edge.

f. Care should be exercised in handling and storing oilstones in order to maintain the original sharpness of the grit. The surface must be kept flat and even and should not be allowed to become glazed. If the stone is kept in a dry place, it should be placed in a closed box and oiled occasionally to prevent it from drying out. The surface is kept even by sharpening tools on the edges of the stone as well as in the middle. If, however, the surface has become irregular, it can be trued by the following method: Secure a piece of cast iron having a true surface and cover this surface with a mixture of emery and water. Place the oilstone upon the block and lap until true. Stones of special shapes may be trued by planing a groove of corresponding shape in a cast-iron block and drawing the stone through the groove, using emery and water.

g. Either oil or water is used on an oilstone to prevent glazing. After using, the stone should be wiped clean with a cloth or waste. If the stone becomes gummed or glazed, it should be washed in gasoline or ammonia, wiped dry, and oiled.

h. Oilstones that are mechanically operated usually require the use of a light, free-flowing oil on their surface. The purpose of this oil is to float the minute particles of material abraded from the work and to keep them in suspension so they will not become imbedded in the surface and form a glaze.

APPENDIX

BIBLIOGRAPHY

Figures 1 to 13, inclusive, 20, 23, 24, 26, 27, 29, 30, 41 to 49, inclusive, 54, 55, and 56. Courtesy of Brown & Sharpe Manufacturing Co., Providence, R. I.

Figures 33 and 40. Courtesy Ex-Cell-O Corporation, Detroit, Mich.

Figure 34. Courtesy Cincinnati Milling Machine and Cincinnati Grinders, Inc., Cincinnati, Ohio.

Figures 31 and 32. Norton Company, Worcester, Mass.

[A. G. 062.11 (9–9–40).]

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:

E. S. ADAMS,
Major General,
The Adjutant General.

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